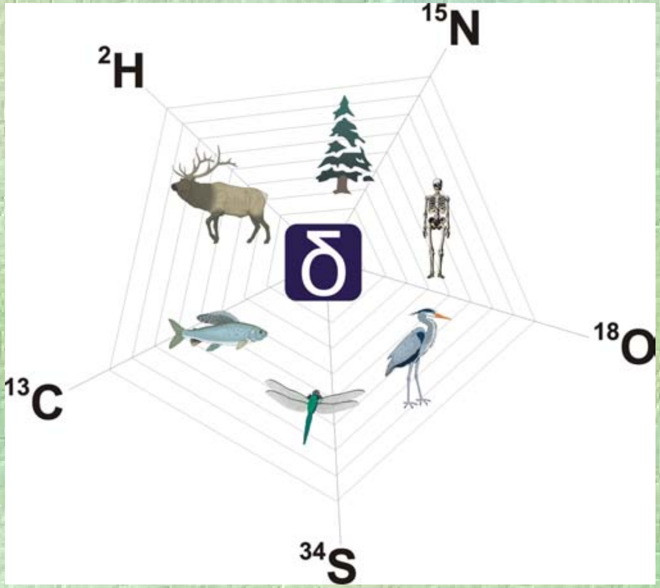
Tracking animal movements using stable isotopes

Keith A. Hobson



Isotopes as endogenous markers

^{12}C

^{13}C — $\delta^{13}C$ (‰)

^{14}N

^{15}N — $\delta^{15}N$ (‰)

^{32}S

^{34}S — $\delta^{34}S$ (‰)

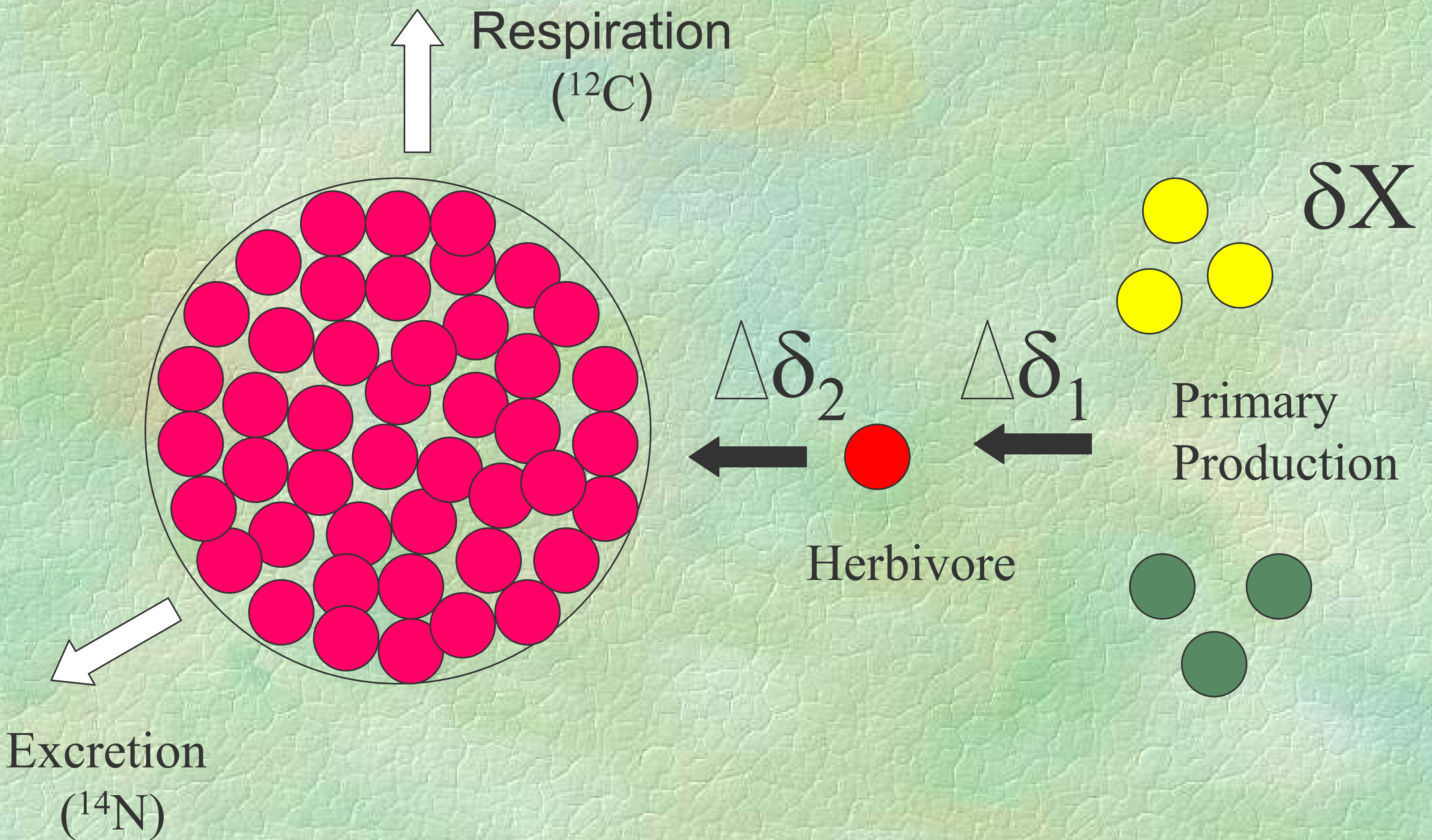
^{16}O

^{18}O — $\delta^{18}O$ (‰)

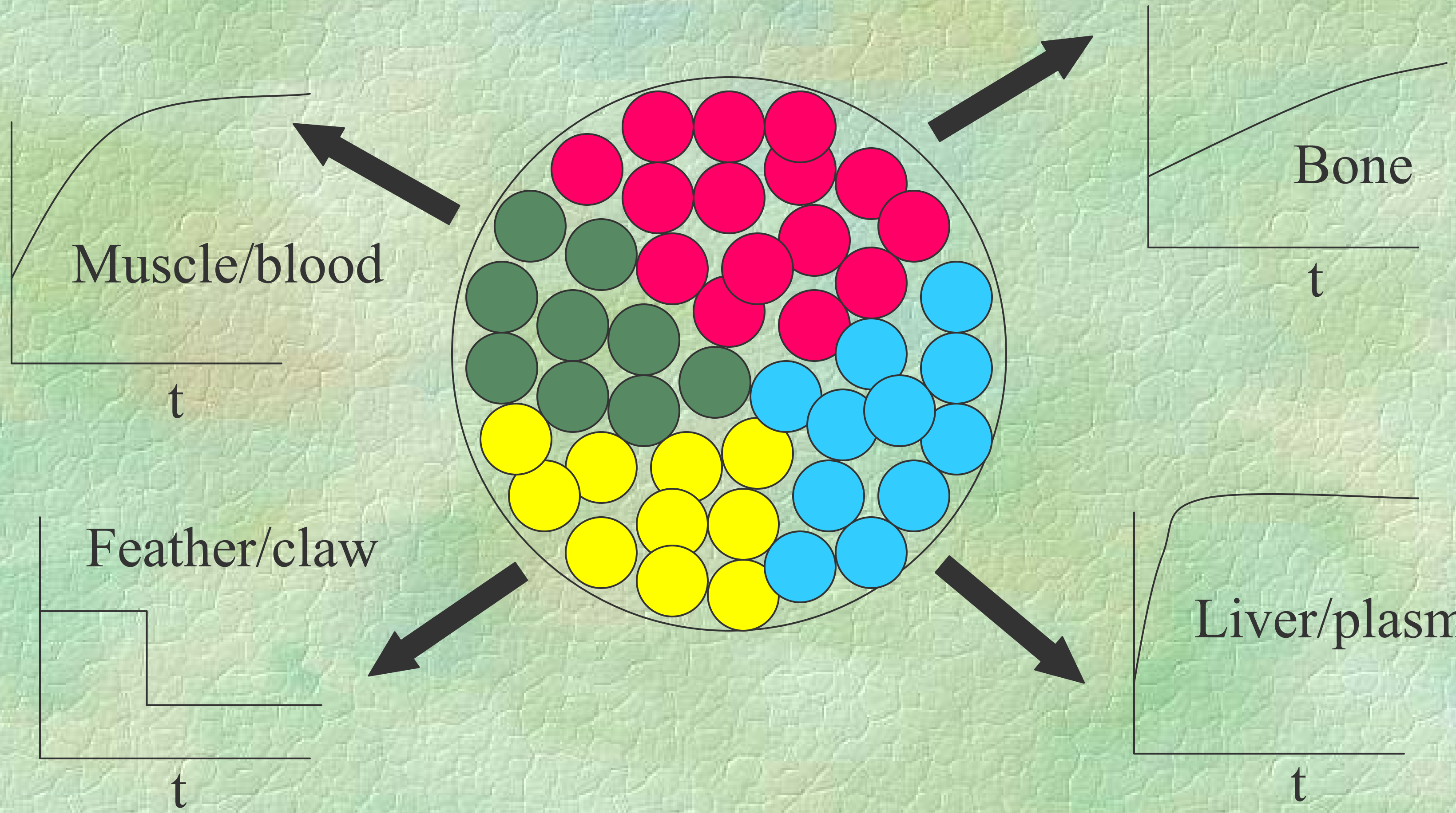
^{1}H

^{2}H — δD (‰)

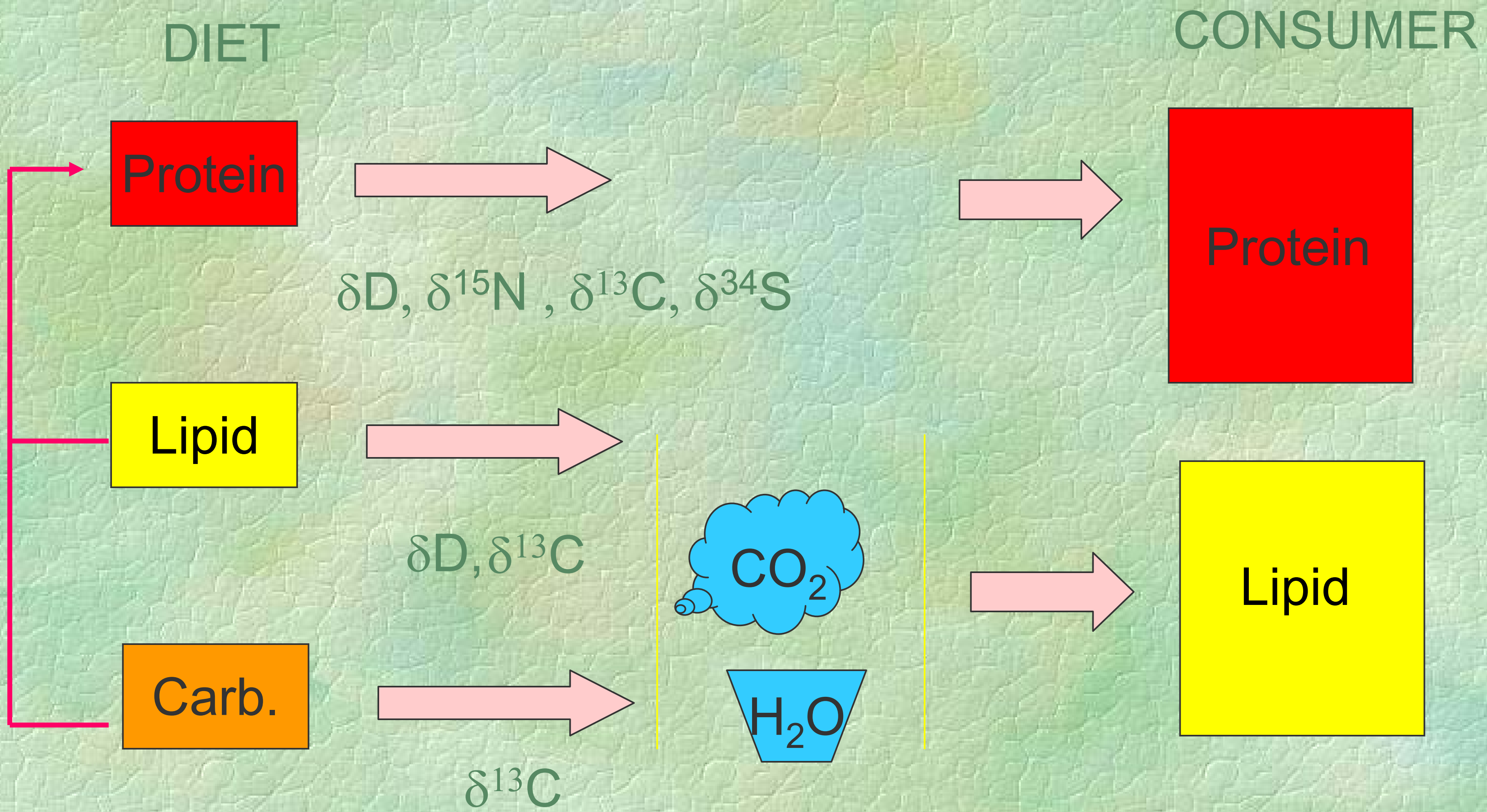
The basic principles of trophic level and source determinaitons



Choice of tissue …..



Metabolic routing: where does the element come from in your isotopic measurements?….

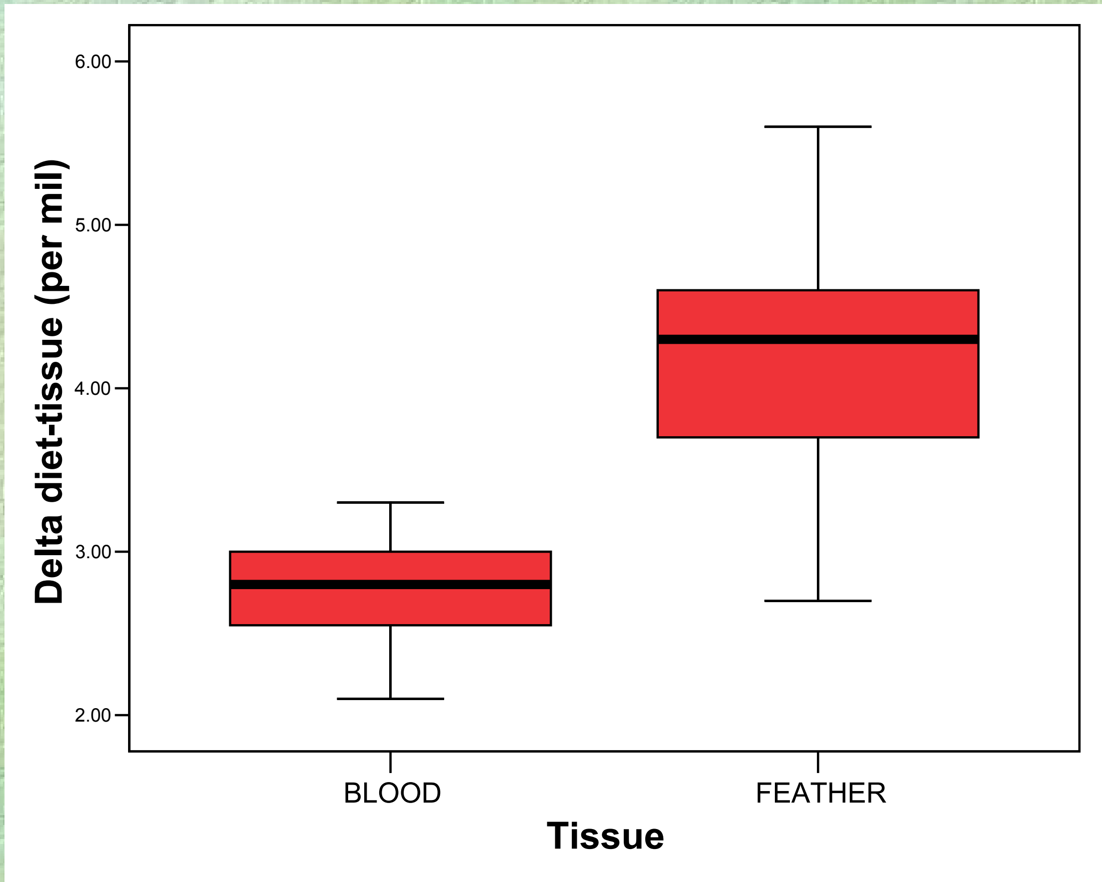


Isotopic discrimination and elemental turnover ….

Stable-N isotope discrimination (non herbivores)

King Penguin
Rockhopper Penguin
Ring-billed Gull
Great Skua
Peregrine Falcon
Garden Warbler

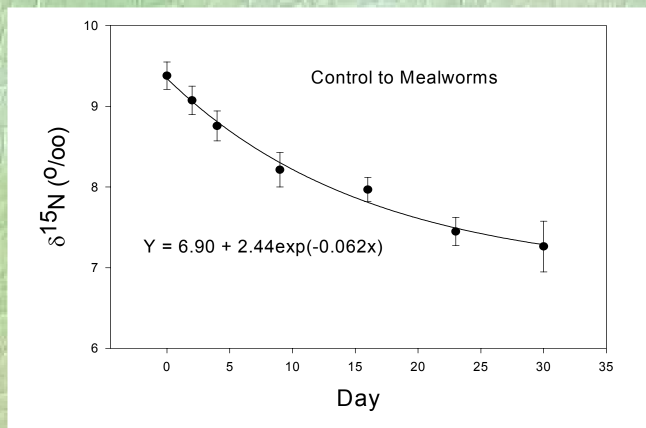
Humboldt's Penguin
King Penguin
Rockhopper Penguin
Common Cormorant
European Shag
Ring-billed Gull
Black-tailed Gull
Great Skua
Nankeen Night Heron
Great White Egret
Grey Heron
Scarlet Ibis
White Ibis
Flamingo
Peregrine Falcon
Garden Warbler

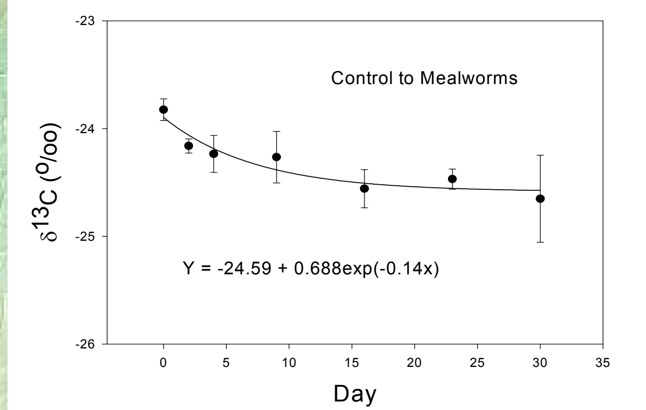


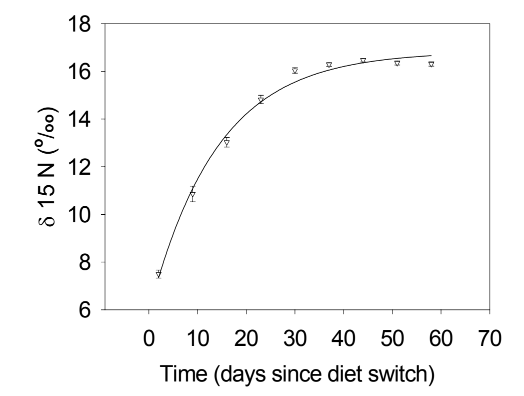
Cherel et al. 2005,Hobson and Clark 1992, Bearhop et al. 2002, Evans-Ogden et al 2004, Hobson and Bairlein 2003, Mizutani et al. 1992.

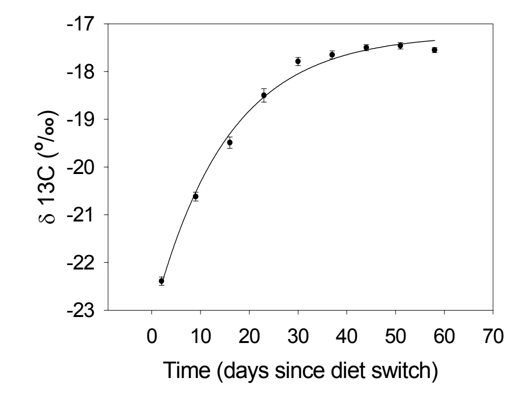
High protein diets:

Tissue	$\Delta\delta^{13}C$	$\Delta\delta^{15}N$	$\Delta\delta D$
Whole Blood	1.5	2.9	?
Plasma	0.5	3.3	?
Muscle	1.9	3.1	?
Feather	2 to 3	3.8	-19 to -35
Claw	?	?	?



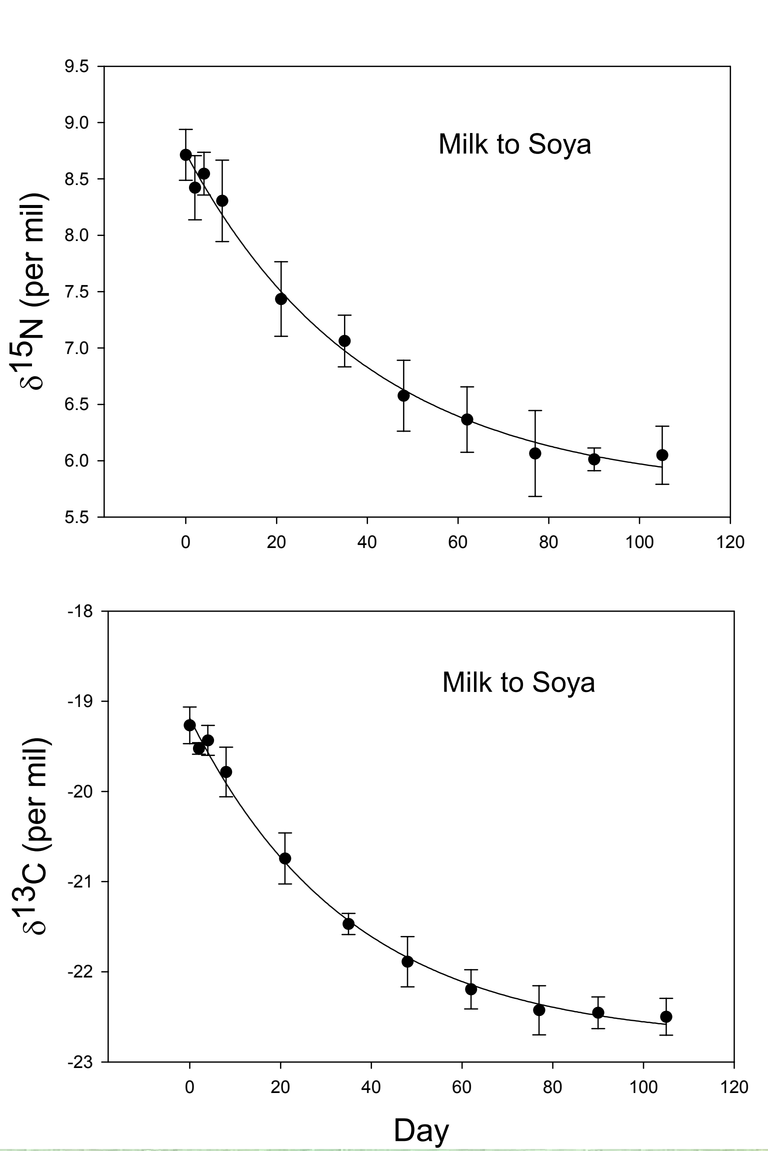






Hobson and Bairlein *CJZ81:1630-1635*

Evans-Ogden et al *Auk* . 121:170-177



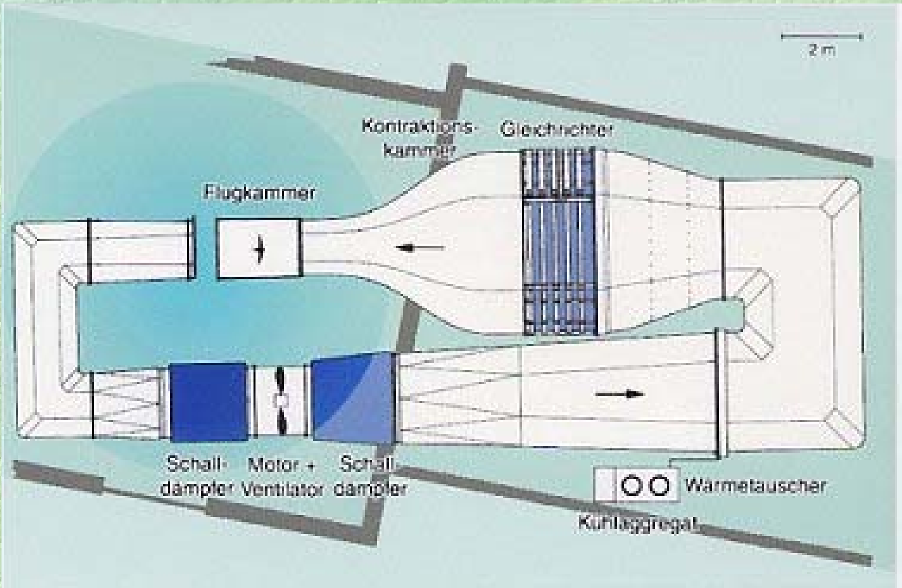
Mirón et al. 2006 J. Exp. Biol

Tissue turnover ….

$$Y = ae^{(-bt)} + c$$

$$T[1/2] = 0.6932/b$$

Using a wind tunnel and isotopic dietary shifts to mimic migration

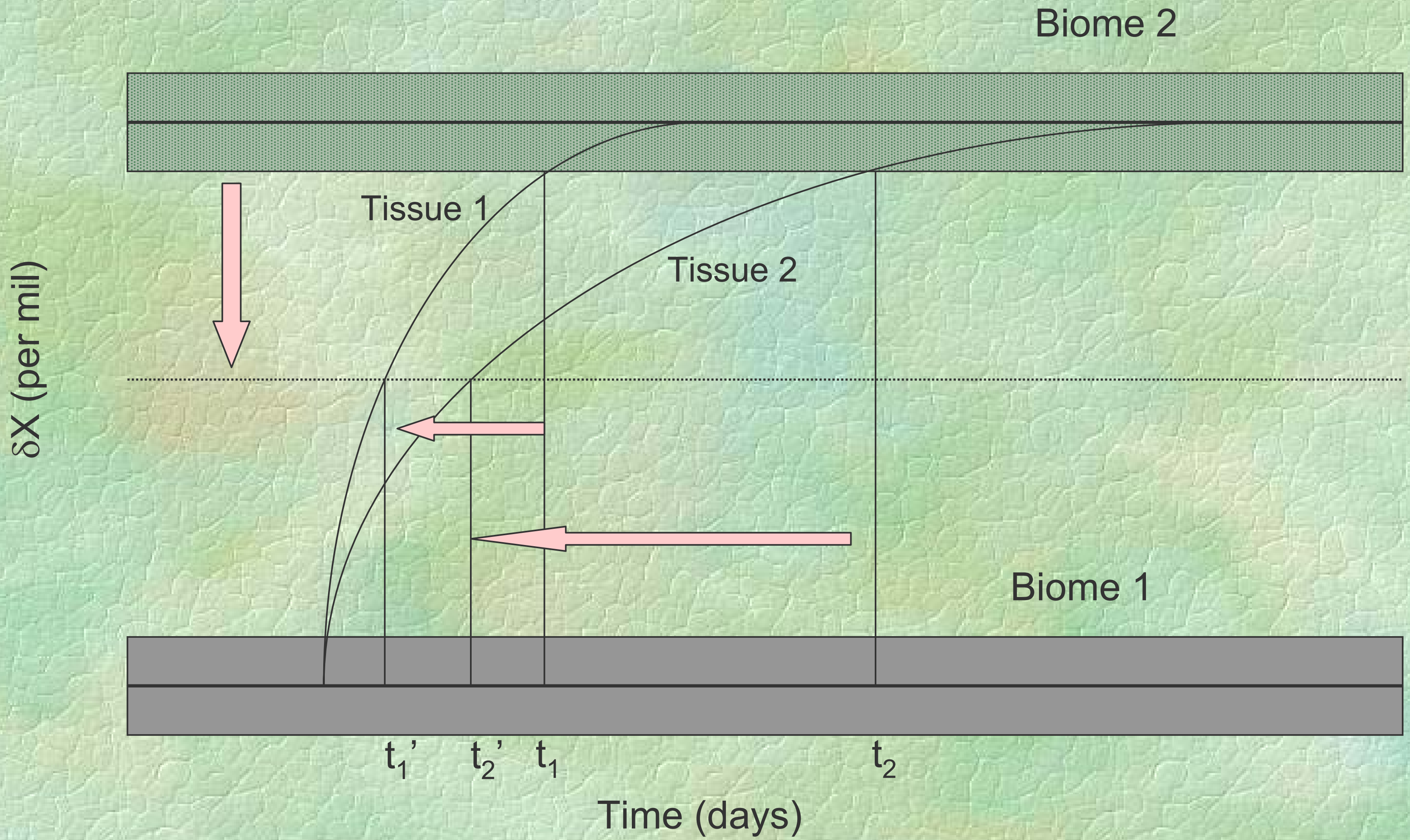


Max Planck Institute for Ornithology

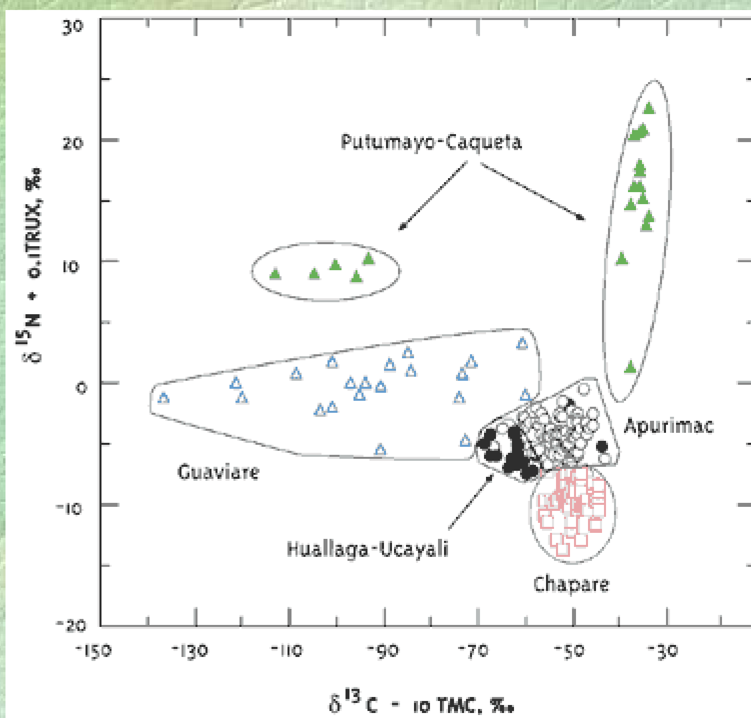
Principles of isotopic tracking

- Animals move between unambiguous isotopically distinct “landscapes” and their tissues retain this information.
- Information “time window” depends on tissue chosen.
- Physiological aspects of movement and migration are understood in terms of turnover, metabolic routing etc.

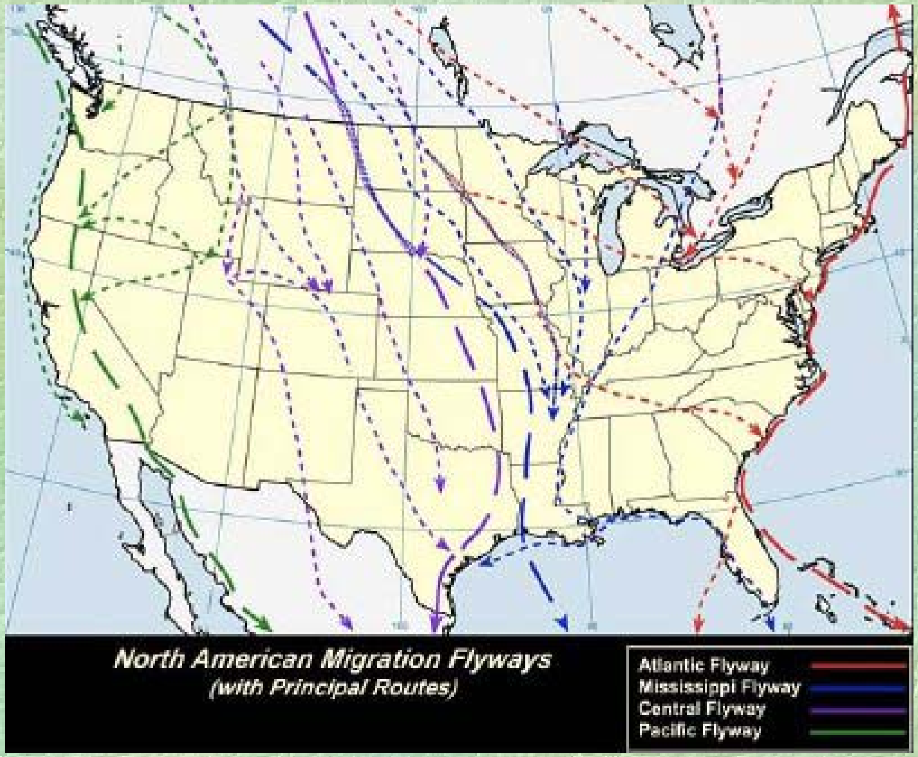
The isotopic clock and movement



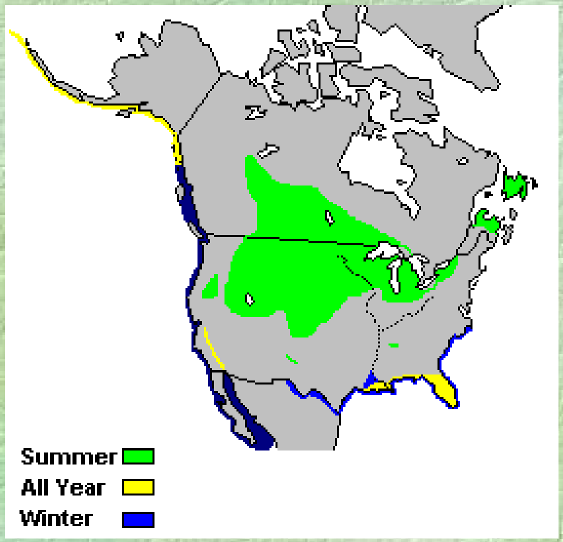
Forensic applications are broad:



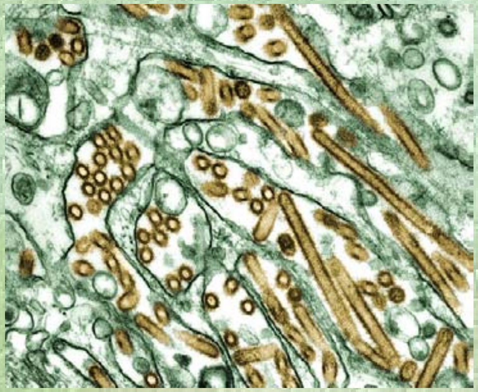
Some avian applications:
1. Game bird management

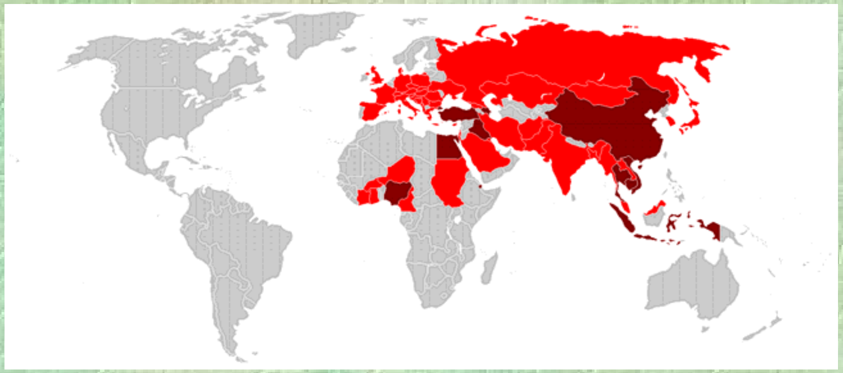


2. Movement of contaminants

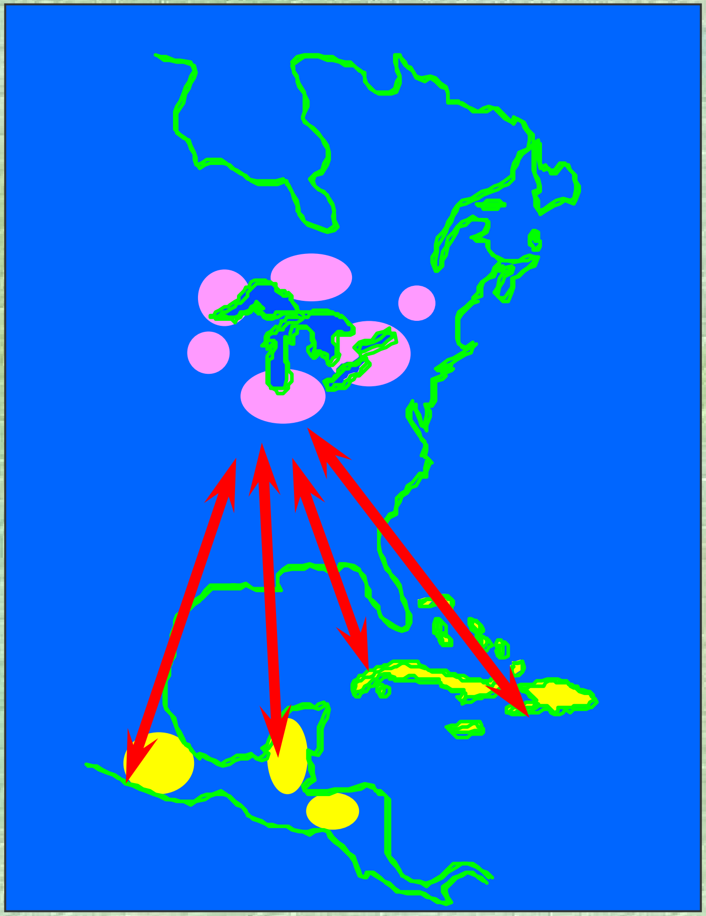
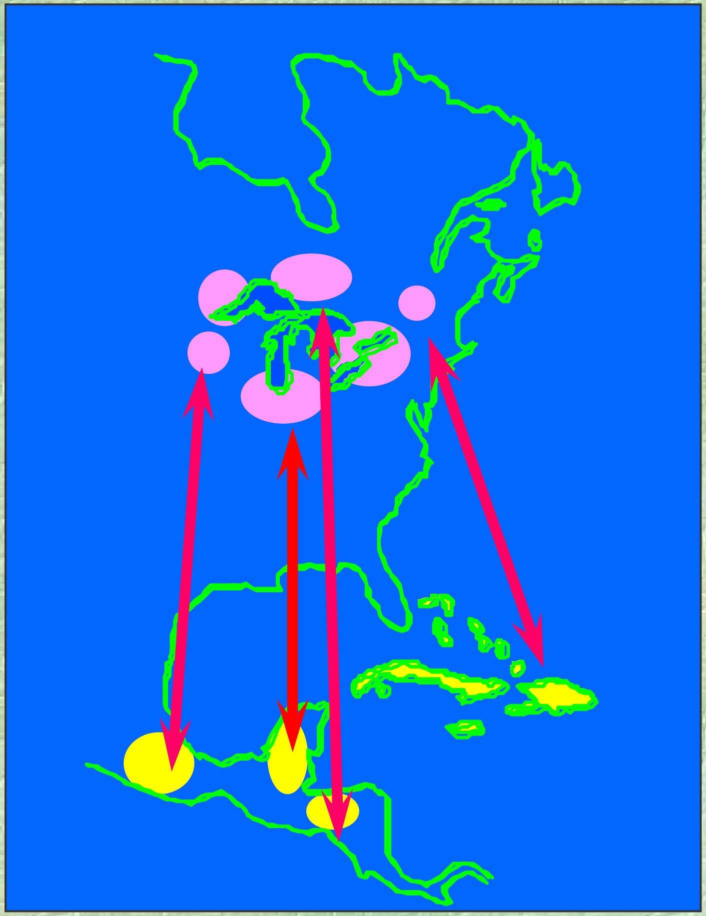


3. Disease tracking: Avian Influenza



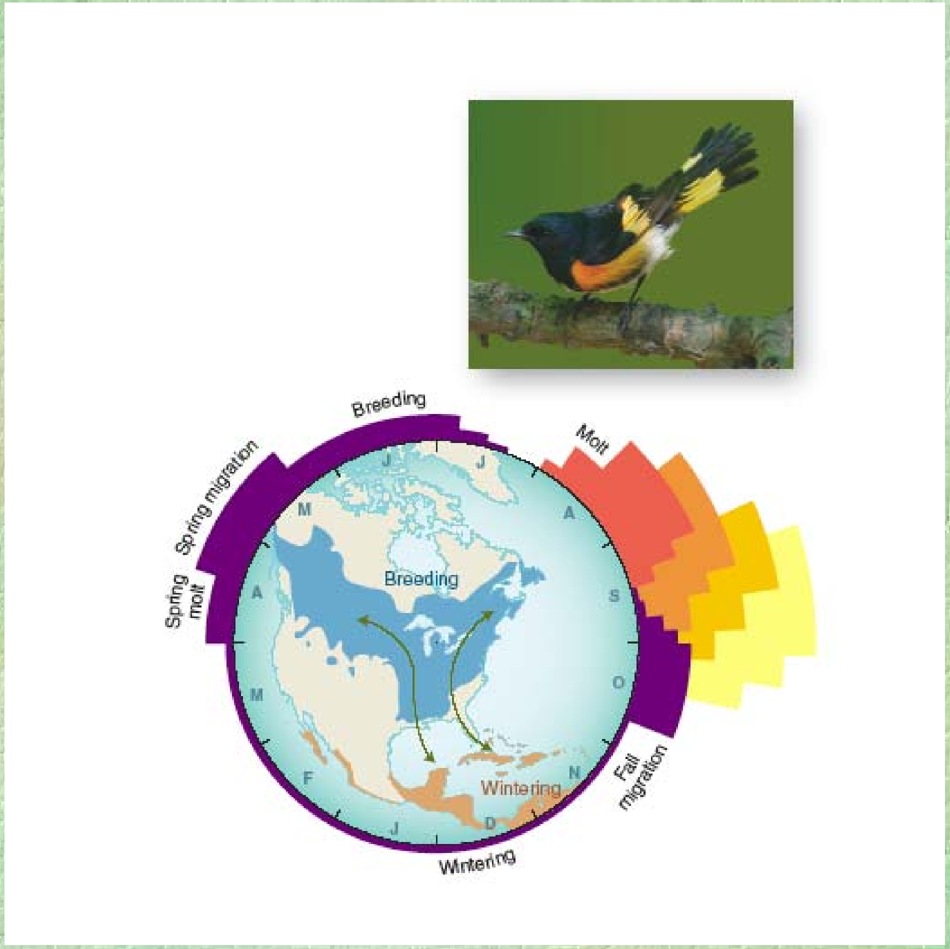


4. Connectivity and stable isotope tracking ....

Idea from Webster et al. *TREE* 17:76-83

5. Seasonal interactions …

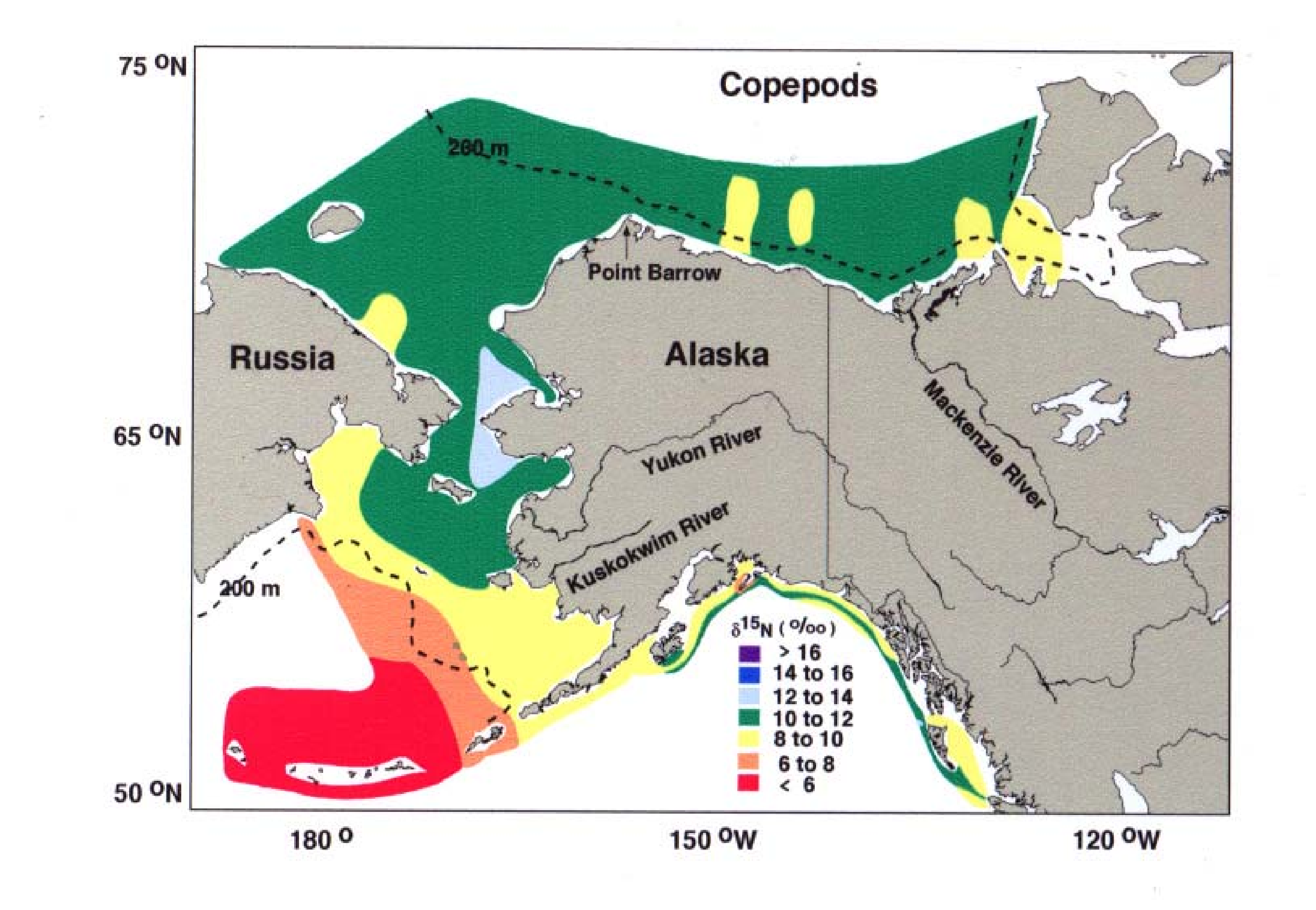


N.A. avian band recoveries (1955-2000)

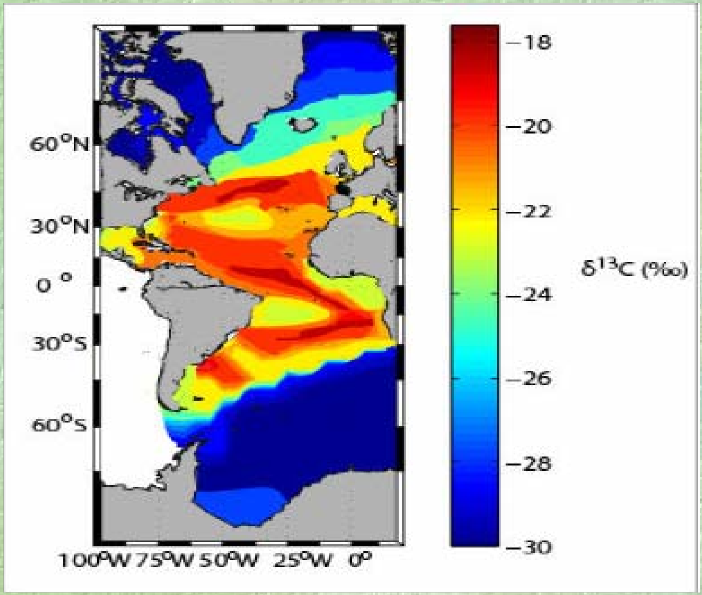
Species	Banded	recap	%
Canada Goose	2,991,538	594,114	19.9
Mallard	5,935,960	878,704	14.8
N. Pintail	1,286,499	142,449	11.1
Merlin	26,308	674	2.6
Logg.shrike	22,897	196	0.86
Sp. sandpiper	13.673	79	0.58
R-t. hummingbird	54,218	53	0.10
Am. redstart	275,222	256	0.09
Myrtle warbler	824,013	704	0.09
W. flycatcher	28,194	20	0.07
Sw. thrush	371,313	251	0.07

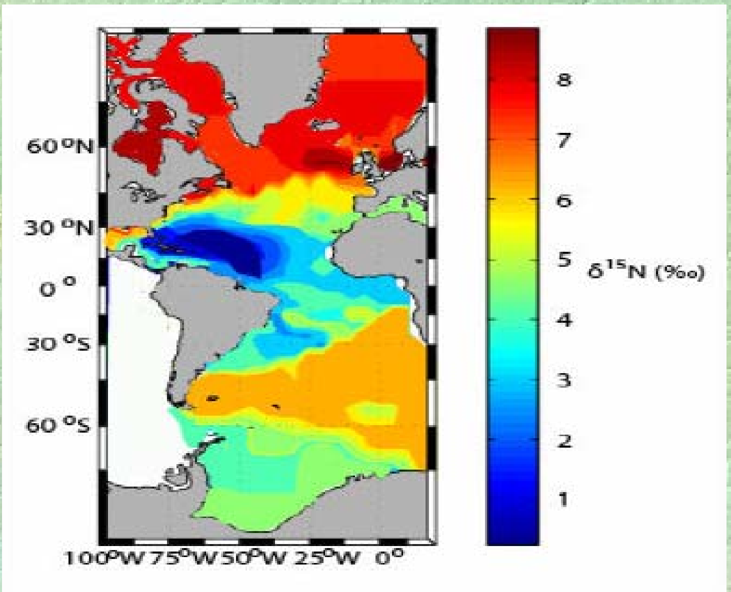
So, banding doesn’t work, Can we use isoscapes?

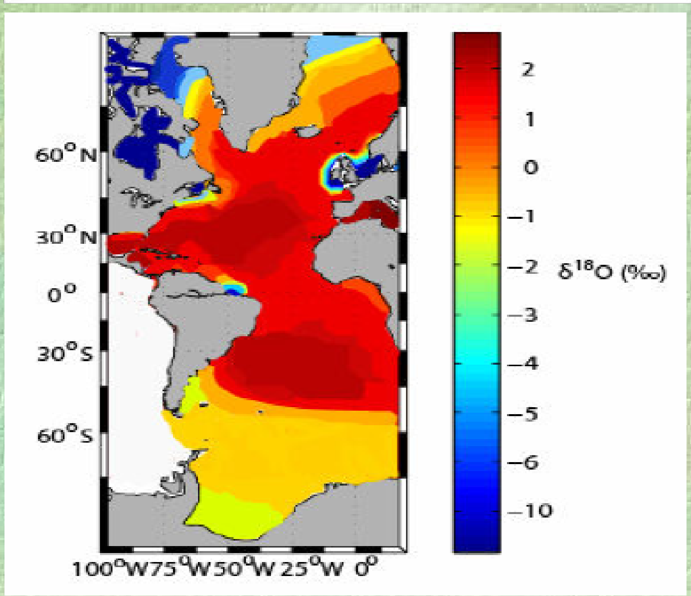
- Terrestrial-marine ($\delta^{13}C$, $\delta^{15}N$ $\delta^{34}S$)
- Inshore-offshore ($\delta^{13}C$, $\delta^{34}S$, $\delta^{15}N$)
- C-3 vs. C-4, CAM ($\delta^{13}C$)
- Xeric vs. Mesic ($\delta^{13}C$, $\delta^{15}N$)
- Latitudinal/altitudinal gradients (δD, $\delta^{13}C$)
- Surficial geology (Sr, Pb, others)



From Schell et al.2002

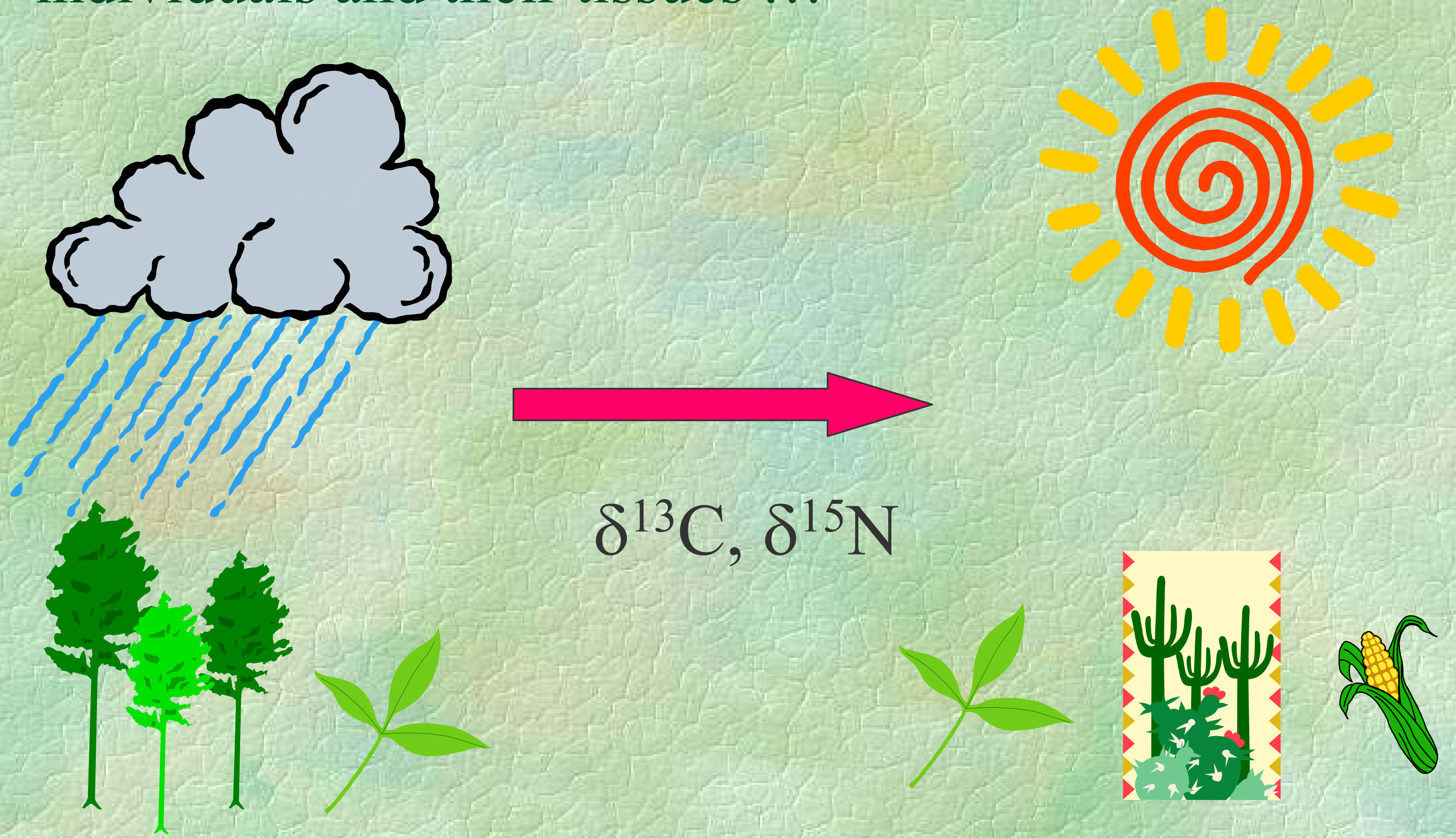




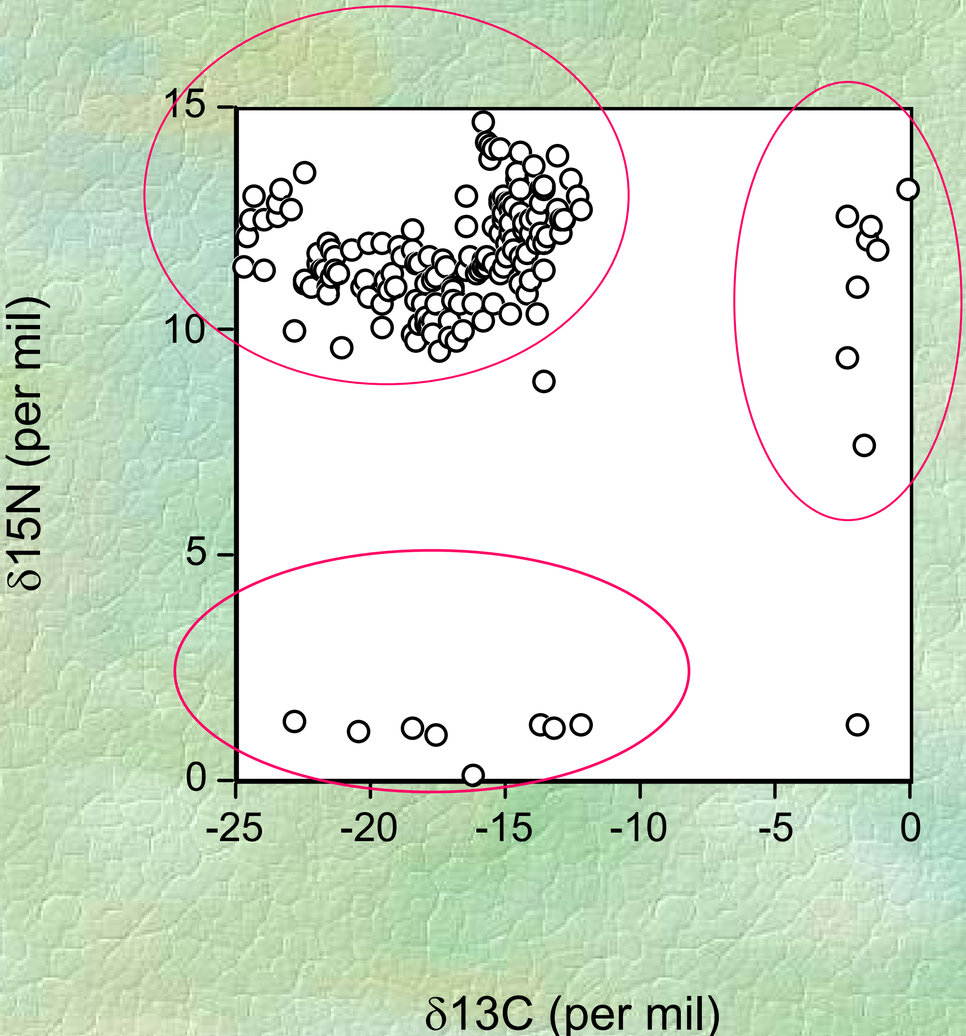


McMahon and Thorrold
Woods Hole

Mesic to xeric isotopic gradients help “locate” individuals and their tissues …

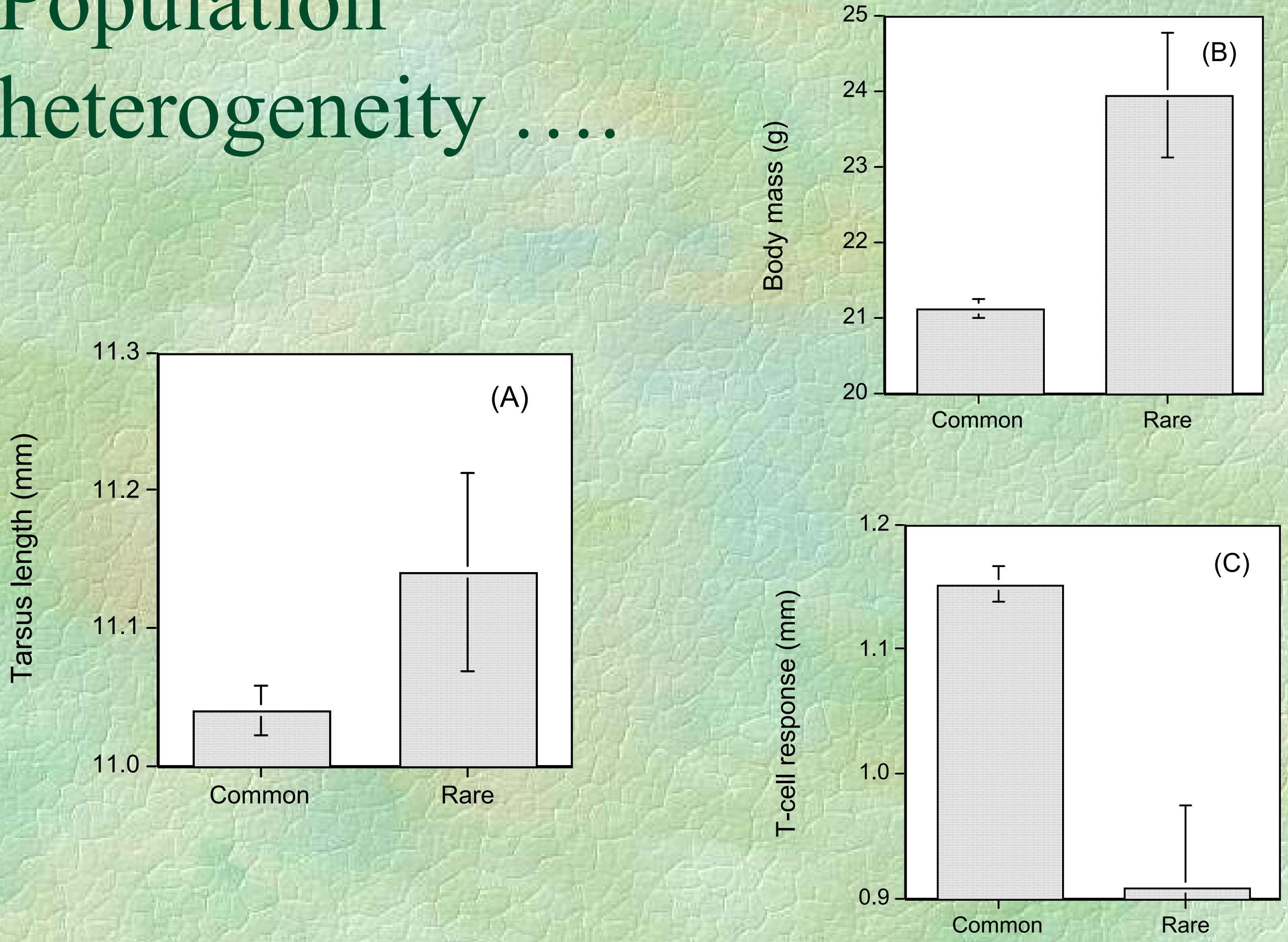


Barn swallows from Denmark are not all wintering in the same part of Africa …



Møller and Hobson (2004)

Population heterogeneity ….



Møller and Hobson (2004)

Using three stable isotopes to distinguish migrants from residents

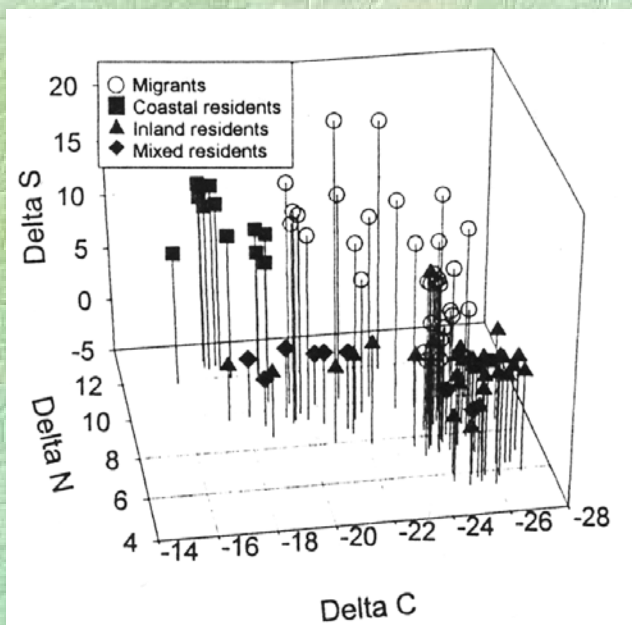


Photo:Wyman Meinzer, USFWS

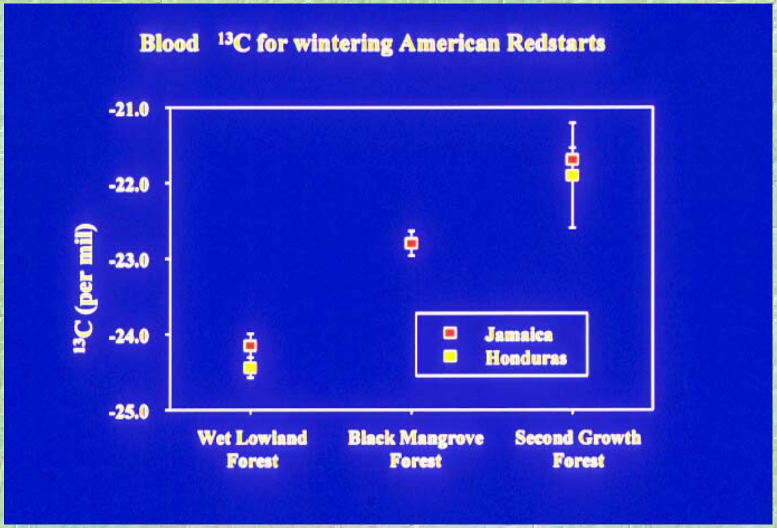
DISTINGUISHING MIGRATORY AND RESIDENT CANADA GEESE USING STABLE ISOTOPE ANALYSIS

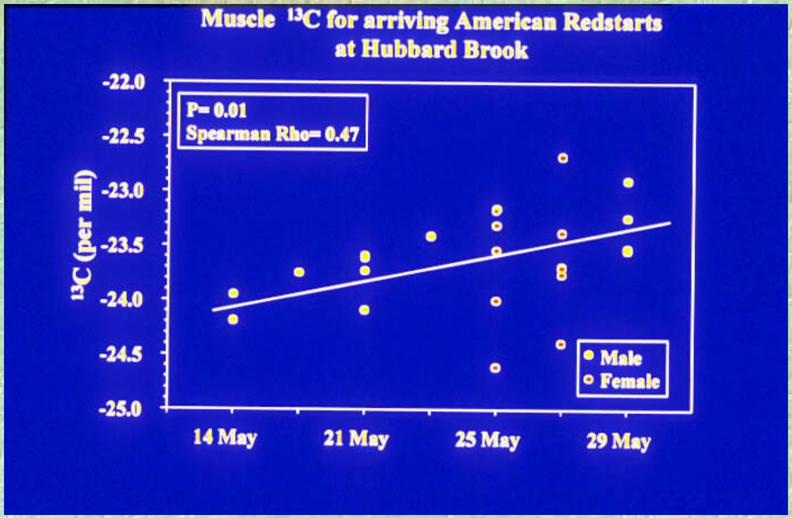
DONALD F. CACCAMISE, Department of Wildlife and Fishery Sciences, New Mexico State University, Las Cruces, NM 88003, USA
LISA M. REED, Department of Entomology, Rutgers University, New Brunswick, NJ 08903, USA
PAUL M. CASTELLI, New Jersey Division of Fish and Wildlife, Nacote Creek Research Station, Port Republic, NJ 08241, USA
SAM WAINRIGHT,[1] Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ 08903, USA
TED C. NICHOLS, New Jersey Division of Fish and Wildlife, L. G. MacNamara Wildlife Management Area, 2201 County Route 631, Woodbine, NJ 08270, USA

Abstract: Effective management of Canada geese (*Branta canadensis*) requires a reliable method to determine the population affiliation of geese in the harvest. We determined if stable isotope analysis of feather tissue could distinguish between migrant and resident populations. We obtained feather samples of migrants from Atlantic population of Canada geese in northern Quebec near Ungava Bay, Canada. We grouped resident population Canada geese as coastal residents and inland residents according to the habitats where they were captured in New Jersey. We analyzed for isotopes of carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$) , and sulfur ($\delta^{34}S$). We found significant differences among migrants, coastal residents, and inland resident for all 3 isotopes. Combinations of isotopic ratios for the 3 elements resulted in unique patterns among groups of geese. We entered the isotopic ratios into a discriminant analysis using collection site as the grouping variable (migrants, inland residents, and coastal residents). We formed 2 significant functions that discriminated among the 3 groups 92% of the time. The first function accounted for most of the variance, and was highly influenced by the isotope ratios for carbon and sulfur. The results indicate that stable isotope analysis of primary feathers can provide a reliable means to discriminate between migratory and resident populations of Canada geese. Stable isotope analysis is a promising technique for identifying the breeding areas of Canada geese, but additional studies are needed to determine inherent variability over broad geographic areas.

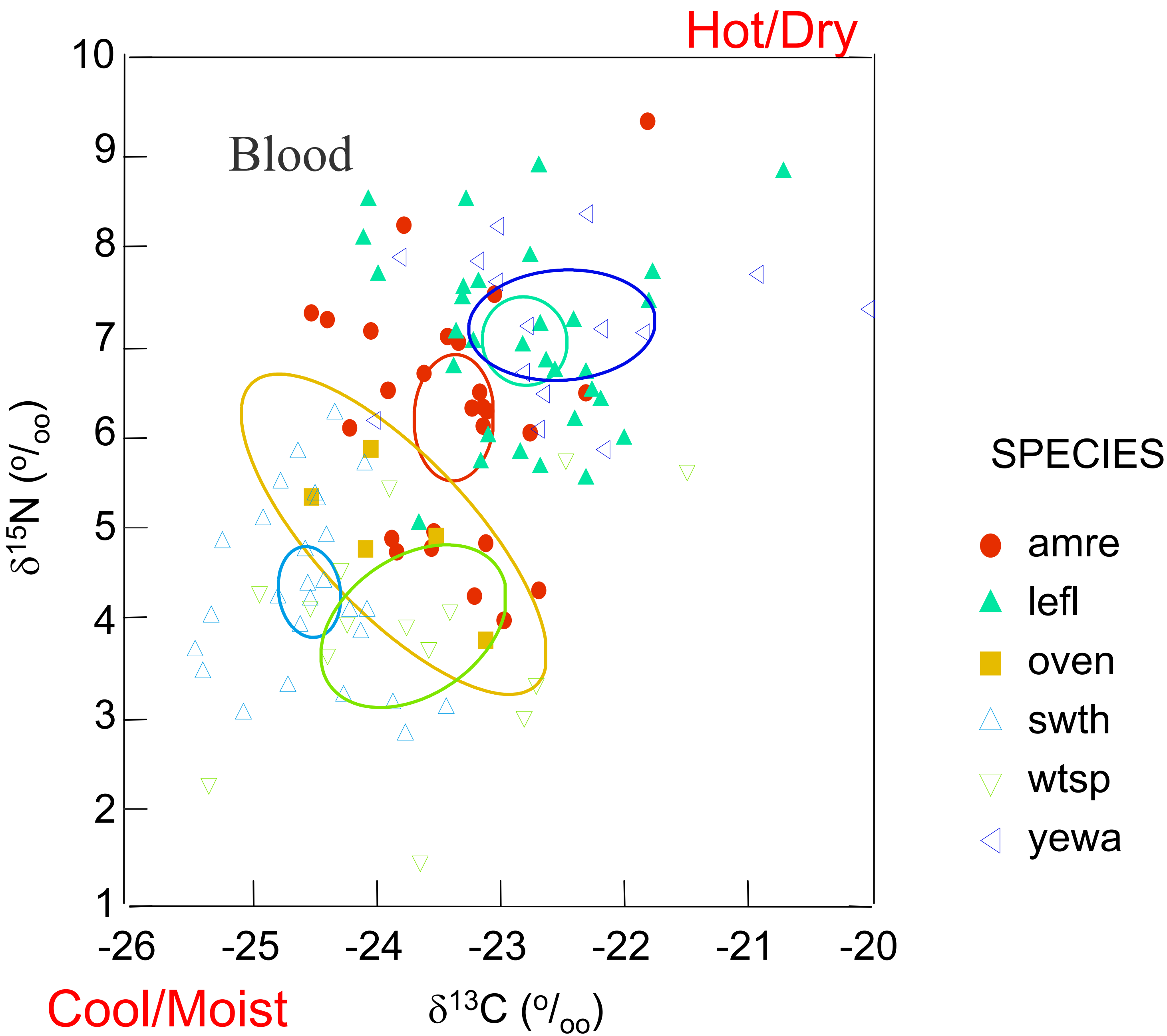
JOURNAL OF WILDLIFE MANAGEMENT 64(4):1084–1091

Wintering habitat determines arrival time on breeding grounds



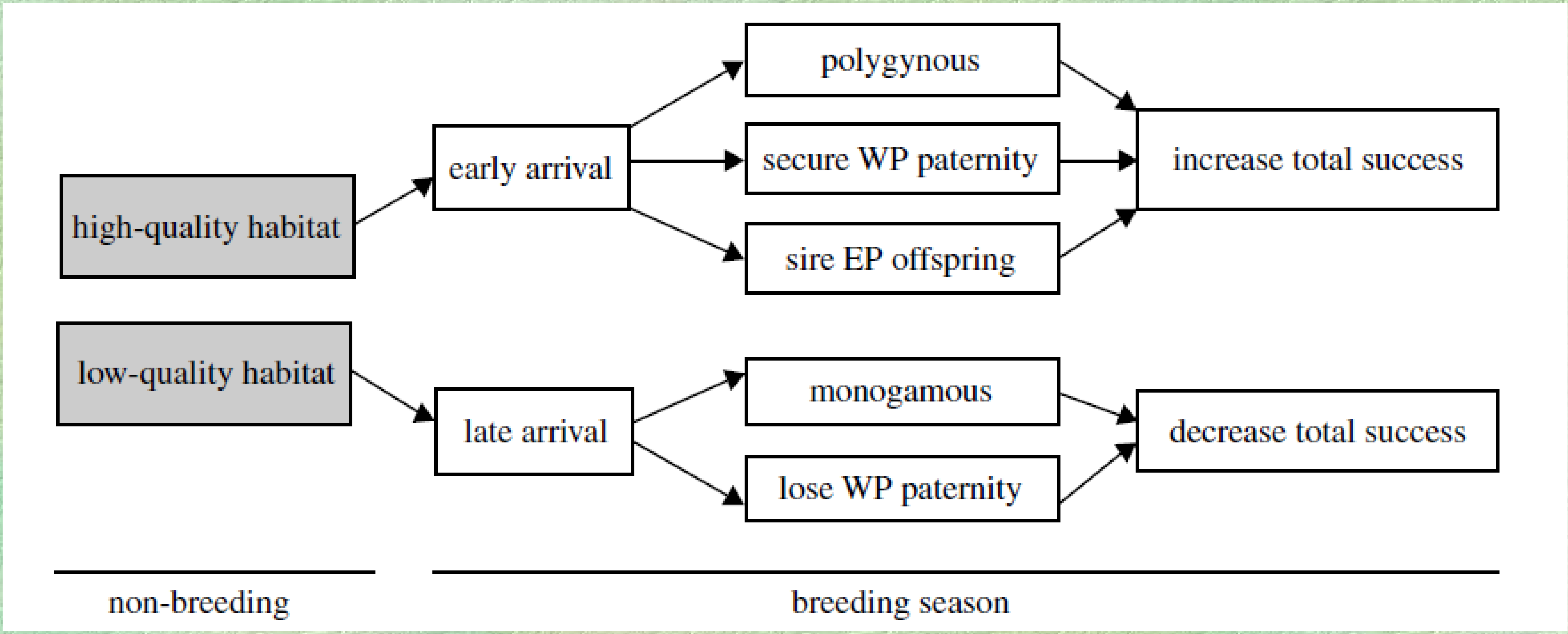


Marra et al. (Science 1998)

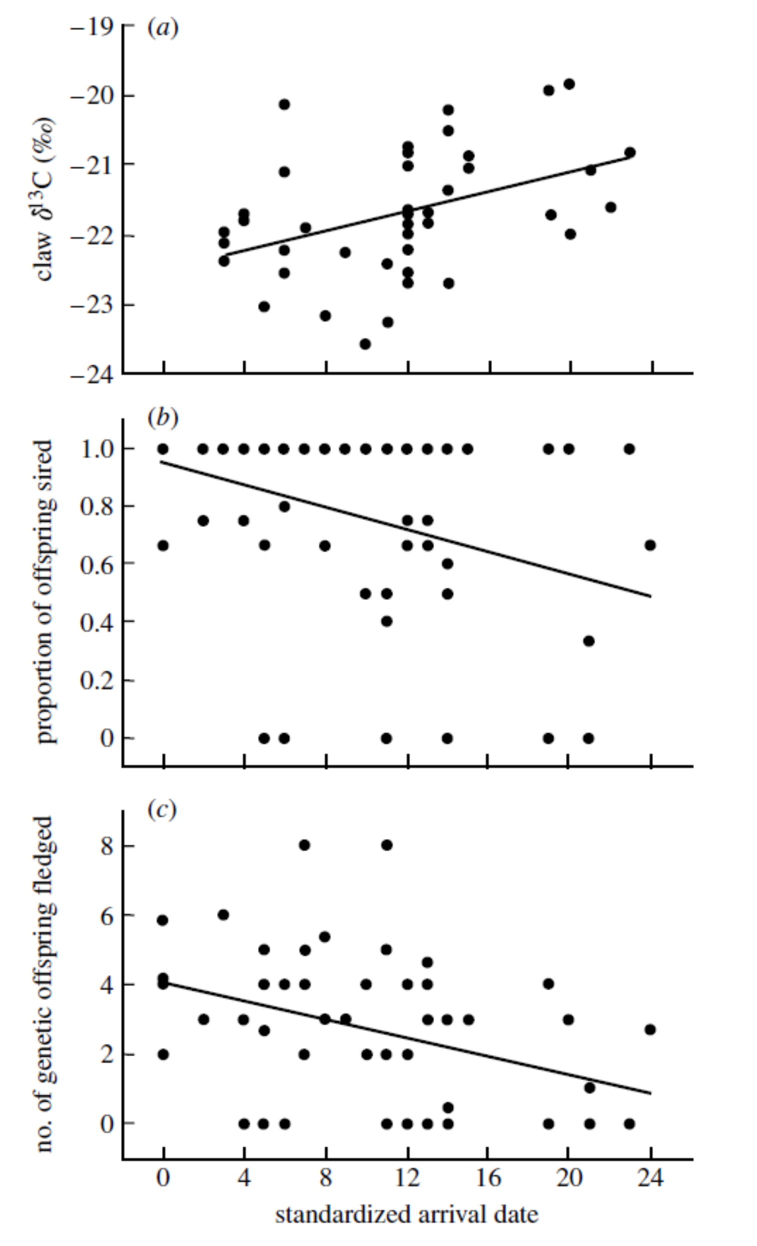


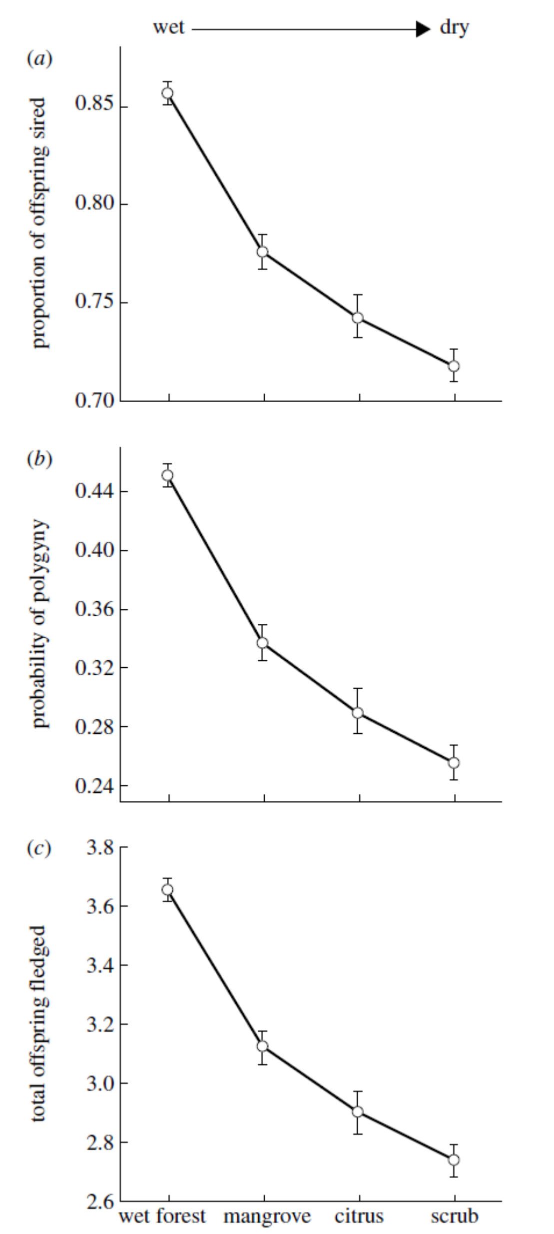
Hot/Dry
Blood
Cool/Moist
δ15N (o/oo)
δ13C (o/oo)
10
9
8
7
6
5
4
3
2
1
-26
-25
-24
-23
-22
-21
-20
SPECIES
amre
lefl
oven
swth
wtsp
yewa

Carry over effects ….



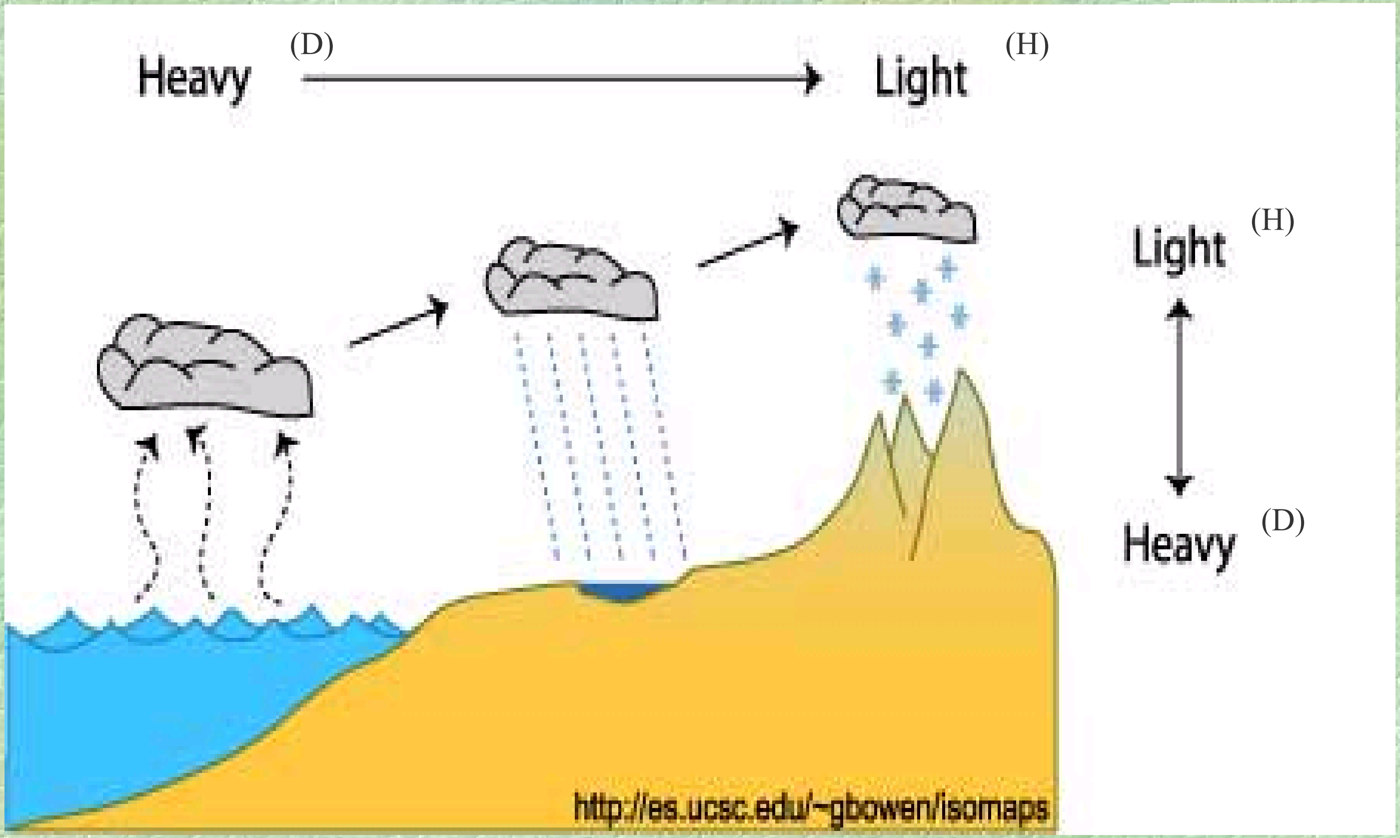
Reudink et al. 2009



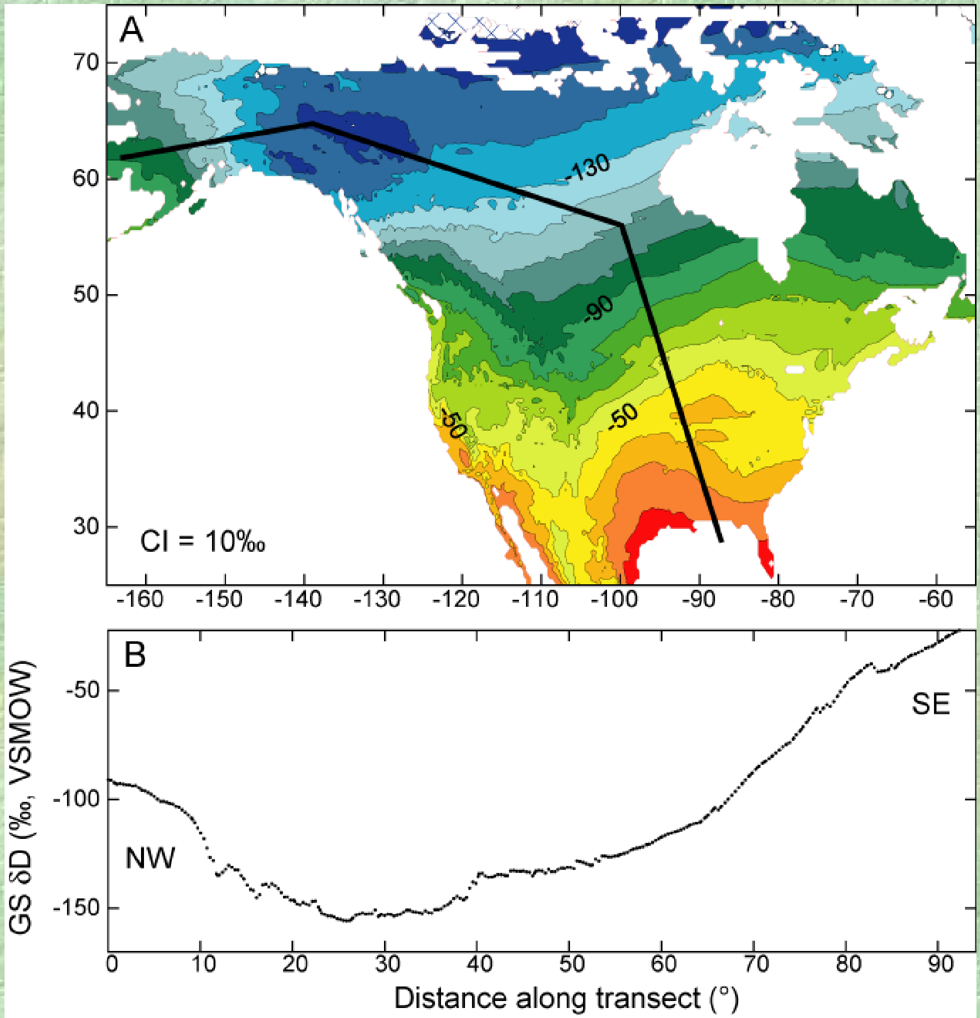


Reudink et al 2009

The BIG breakthrough: Using deuterium …..

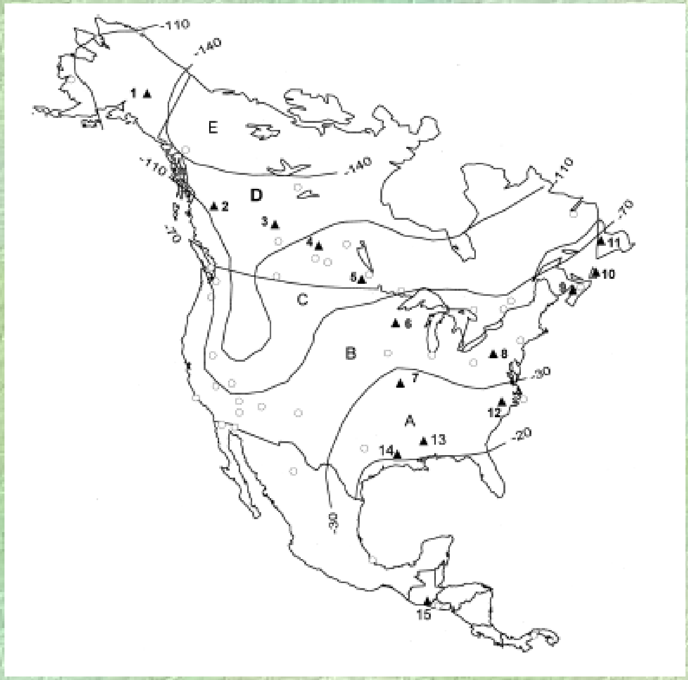


The mean annual precipitation δD pattern:

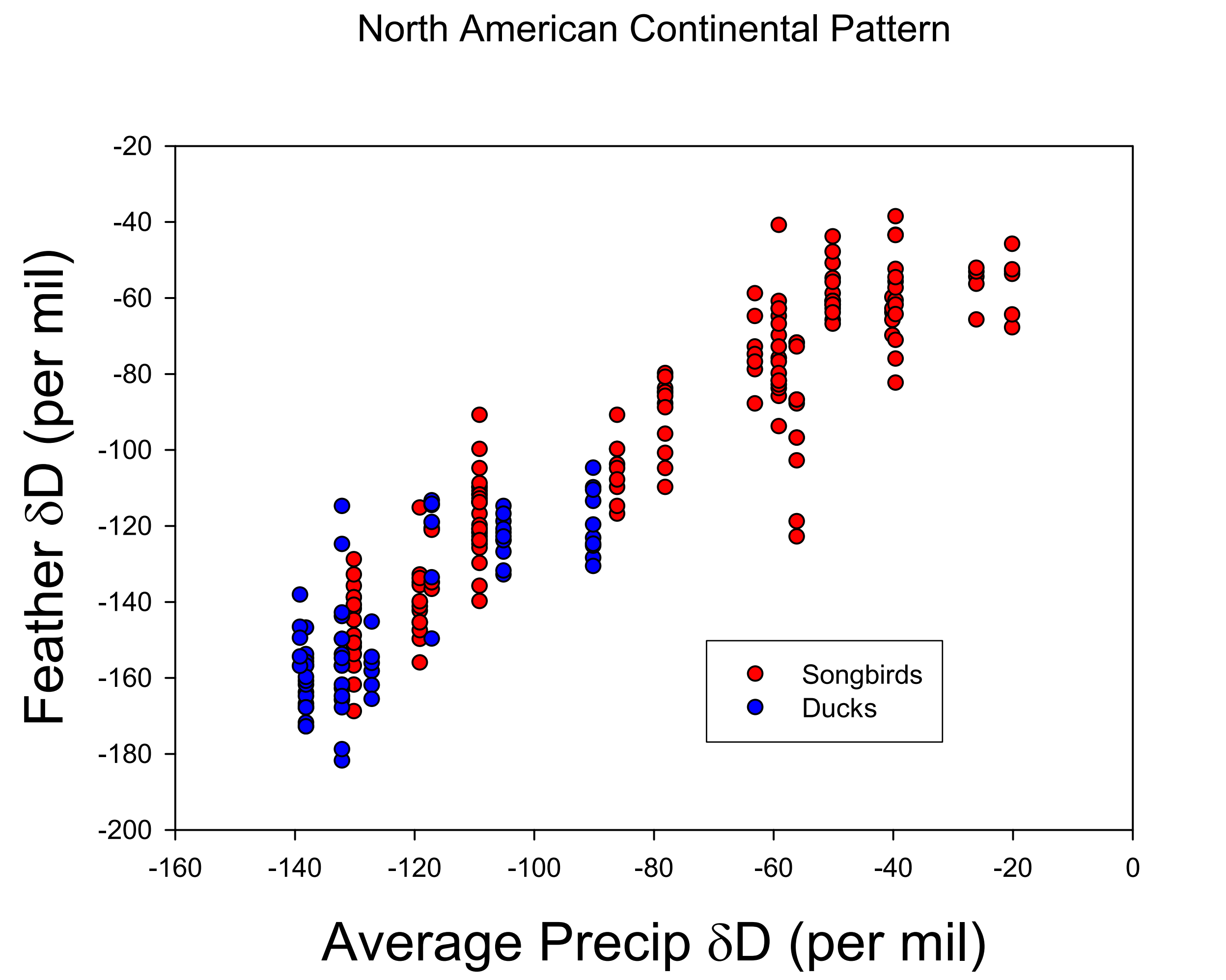


Bowen et al. 2005

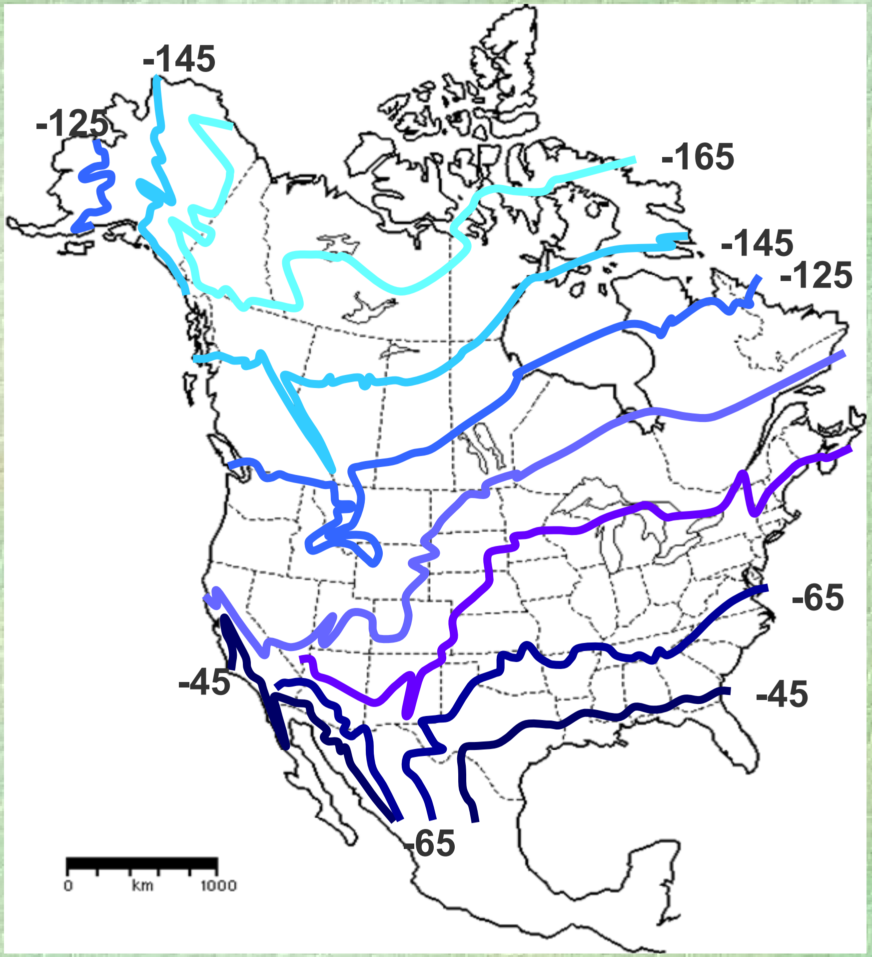
How does this pattern translate into bird feathers?



Hobson and Wassenaar *Oecologia* 109:142-148

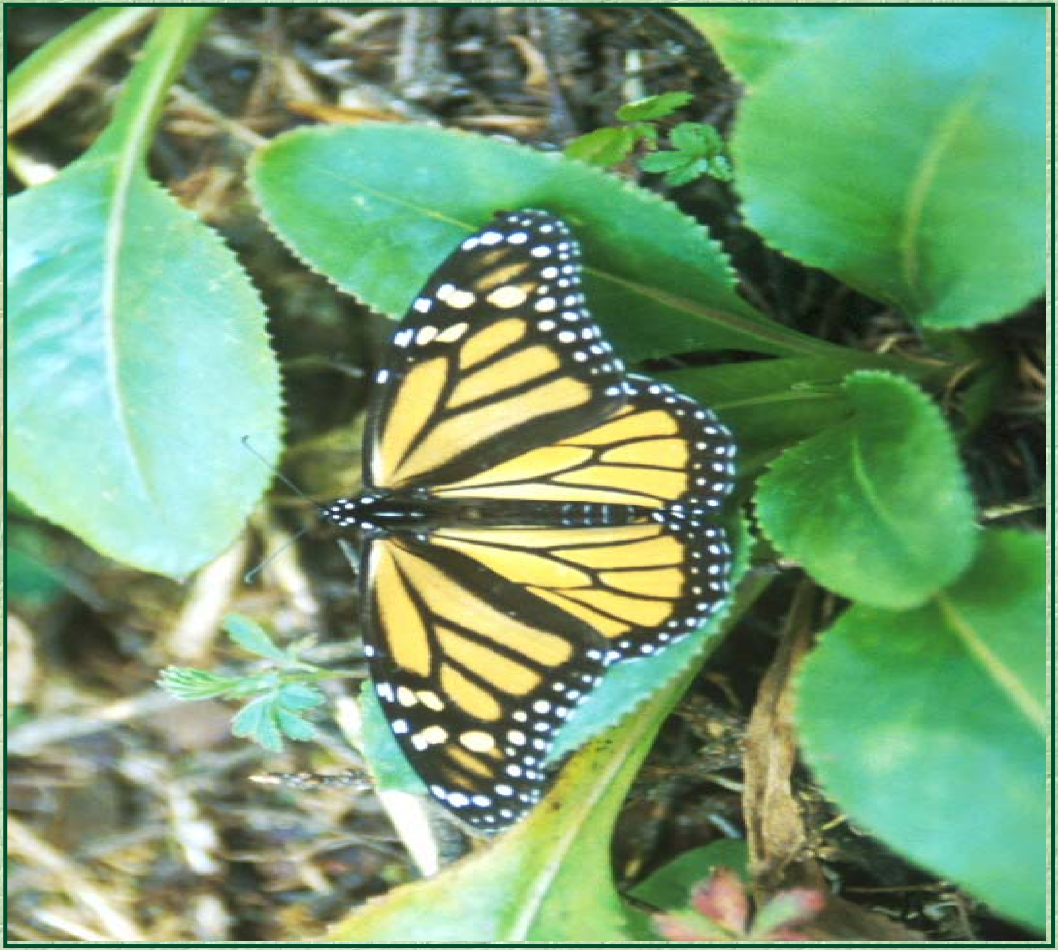

North American Continental Pattern
Feather δD (per mil)
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-160
-140
-120
-100
-80
-60
-40
-20
0
Songbirds
Ducks
Average Precip δD (per mil)

For most birds …



Species	Equation	r^2	Model	Source
Birds:				
6 species of North American songbird	δD=-31 + 0.9δDp	0.83	H	Hobson and Wassenaar (1997)
6 species of North American songbird	δD=-25 + 0.9δDp	0.88	B	Clark et al. (2006)
6 species of North American songbird	δD=-19.4 + 1.07δDp	0.86	B	Bowen et al. (2005)
Black-throated Blue Warbler	δD=-51 + 0.5δDp	0.86	CH	Chamberlain et al. (1997)
Red-winged blackbird	δD=-27 + 1.1δDp	0.83	H	Wassenaar and Hobson (2000)
Bicknell's Thrush	δD=-26 + 0.7δDp	0.48	H	Hobson et al (2001)
Wilson's Warbler	δD=-51.7 + 0.4δDp	0.36	B	J. Kelly (unpublished)
Wilson's Warbler	δD=+14.47 + 1.41δDp	0.91	M	Paxton et al. (2007)
Wilson's Warbler	δD=-21 + 0.7δDp	0.48	M	Meehan et al. (2004)
Mountain Plover	δD=+17.4 + 1.26δDp	0.36	B	Wunder (2007)
23 species of European birds	δD=-7.8 + 1.27δDp	0.65	B	Hobson et al. (2004d)
23 species of European birds	δD=-22.3+0.77δDp	0.85	B	Bowen et al. (2005)
Cooper's Hawk	δD=-34 + 1.0δDp	0.83	H	Meehan et al. (2001)
Inland generalist raptors	δD=-40+0.62δDp	0.59	H	Lott et al. (2003)
Inland bird-eating raptor	δD=-44.2+0.54δDp	0.37	H	Lott et al. (2003)
Coastal generalist raptors	δD=-38.8+0.55δDp	0.19	H	Lott et al. (2003)
Coastal bird-eating raptors	δD=-104.7-0.59δDp	0.12	H	Lott et al. (2003)
Non-coastal bird-eating raptors	δD=-41.1+0.58δDp	0.46	H	Lott et al. (2003)
9 species of raptors	δD=-52.2+0.28δDp	0.09	H	Lott et al. (2003)
9 species of diurnal raptors	δD=-37 + 0.6δDp	0.51	M	Meehan et al. (2004)
Raptors in South Carolina	δD=-25 + 0.7δDp	0.18	M	Meehan et al. (2004)
Flammulated Owl	δD=-8 + 0.9δDp	0.66	M	Meehan et al. (2004)
12 species of raptors	δD=-5.6 + 0.91δDp	0.62	M	Lott and Smith (2006)
Scaup	δD=-27.8 + 0.95Dp	0.64	B	Clark et al. (2006)
Mallards and Northern Pintail	δD=-57 + 0.835Dp	0.56	M	Hebert and Wassenaar (2005)
Other animals:				
Deer collagen	δD= 4 + 1.02δDp	0.94	C	Cormie et al. (1994)
Hoary bat	δD=-25 + 0.8δDp	0.60	M	Cryan et al. (2004)
Monarch butterfly	δD=-79 + 0.62δDp	0.69	H	Hobson et al. (1999)
Beetle (chitin)	δD=33.2 + 1.60δDp	0.74	B	Gröcke et al. (2006)

Using δD to track Monarch migration ….



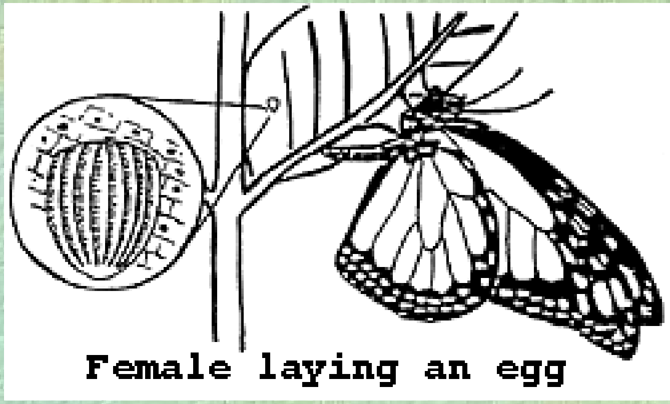
Two populations, one long distance journey ….

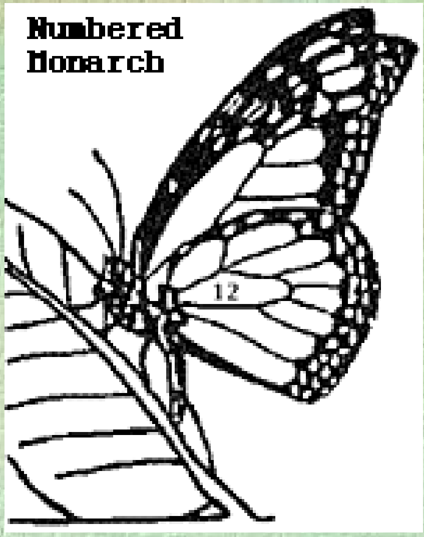
Previously, tagging was used:

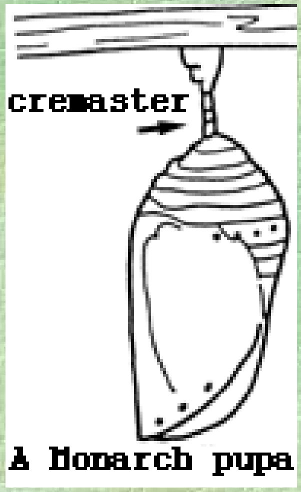
Needle in a haystack?

How to create an isotopic base map?

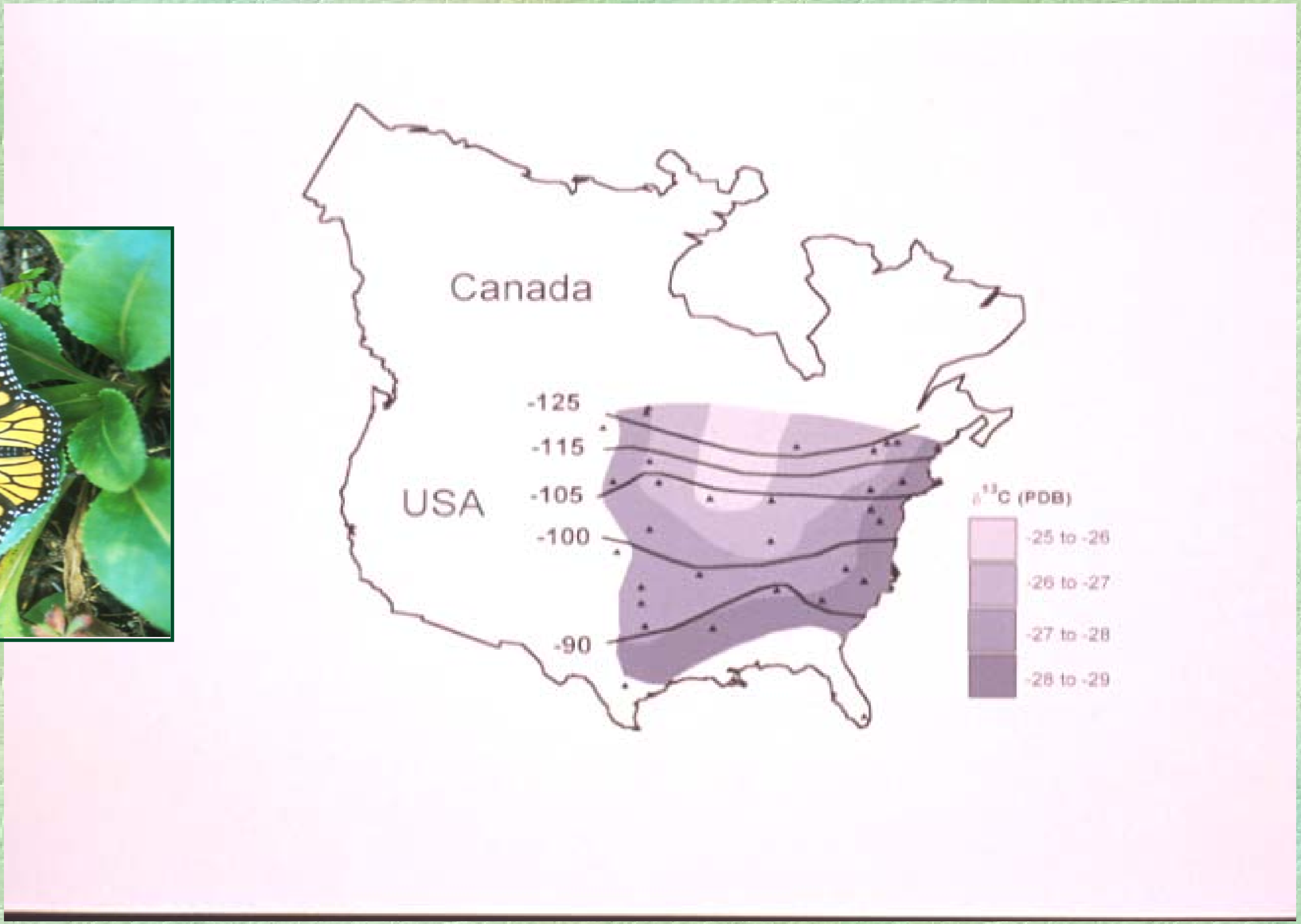
Monarchs can be "grown" anywhere!



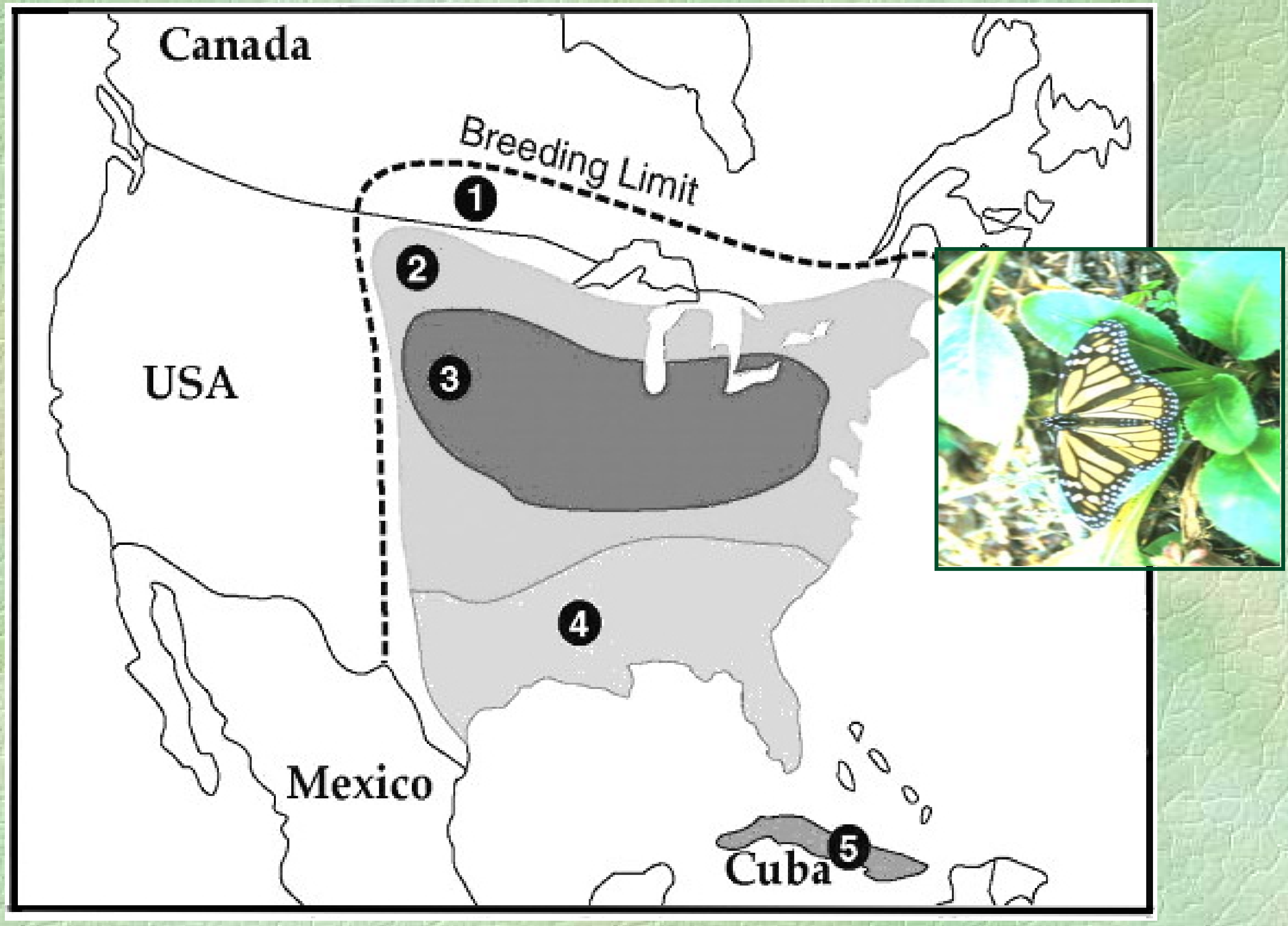




The basemap for the year of interest:

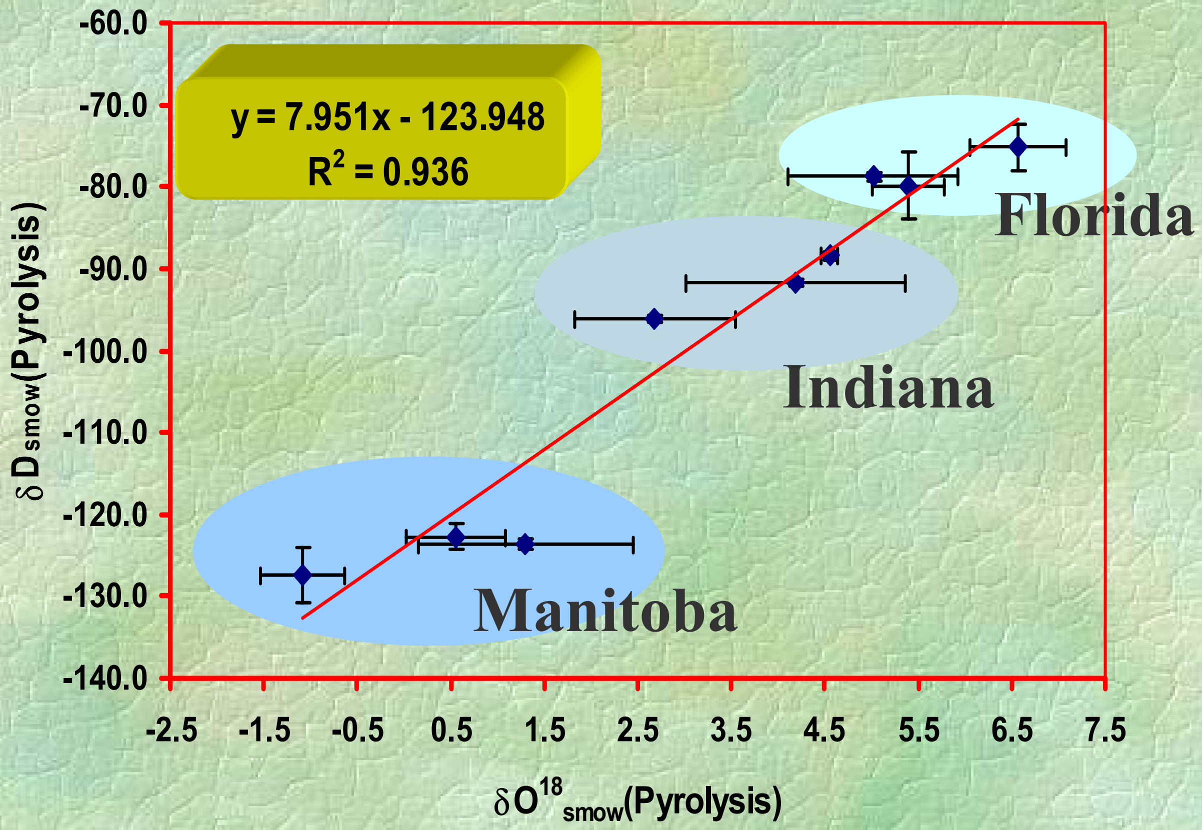


Origins: 50% of the population is produced in the US cornblelt:

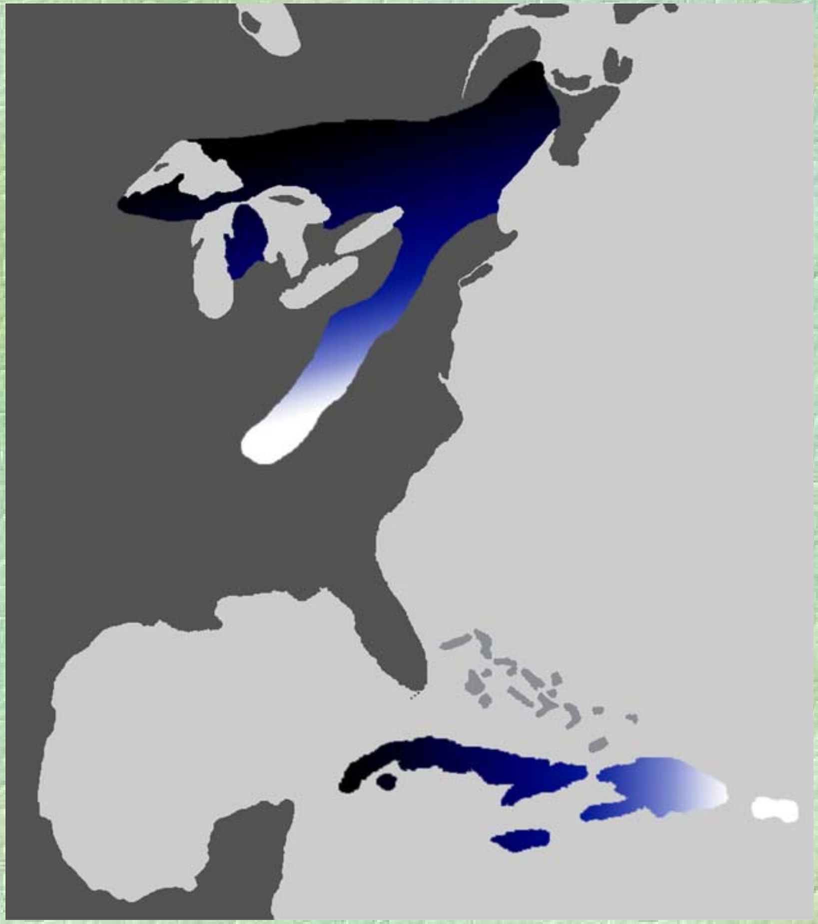


Docykx et al. Ecol. Applic., in press

Meteoric relationship preserved in Monarch Butterflies



Other isotopic delineations of population structure …

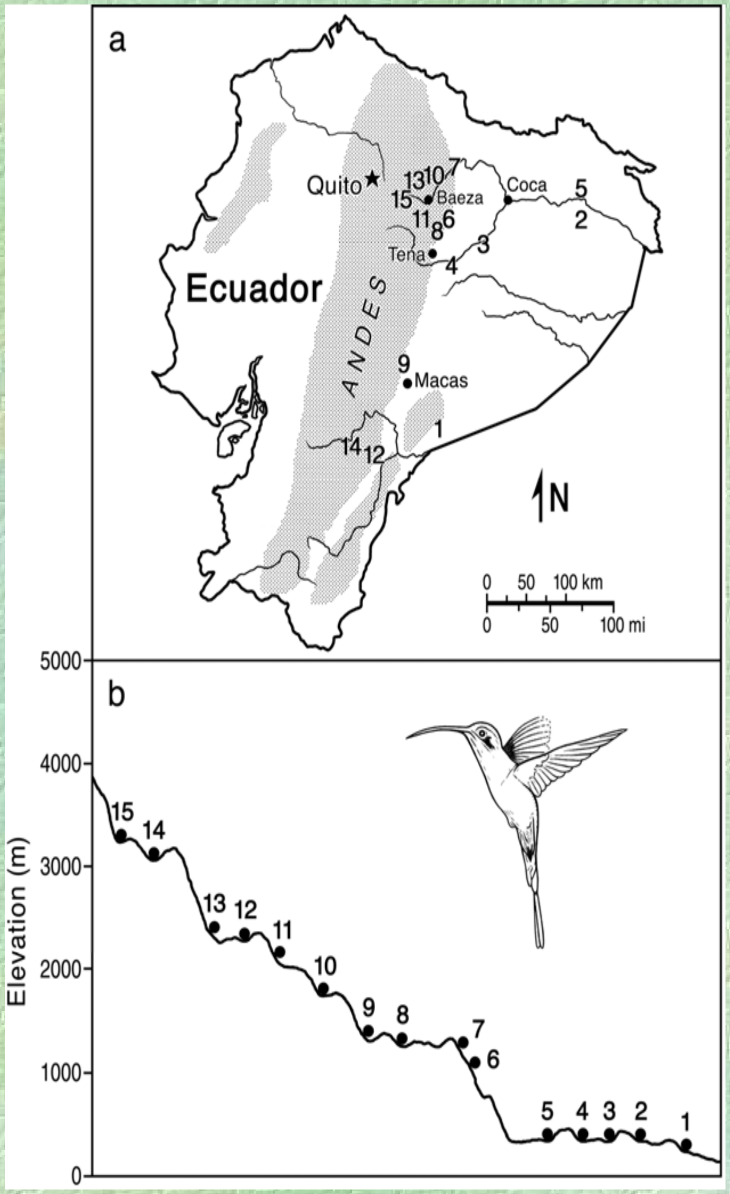


Rubenstein et al. (Science 2002)

"Leapfrog" migration revealed ..

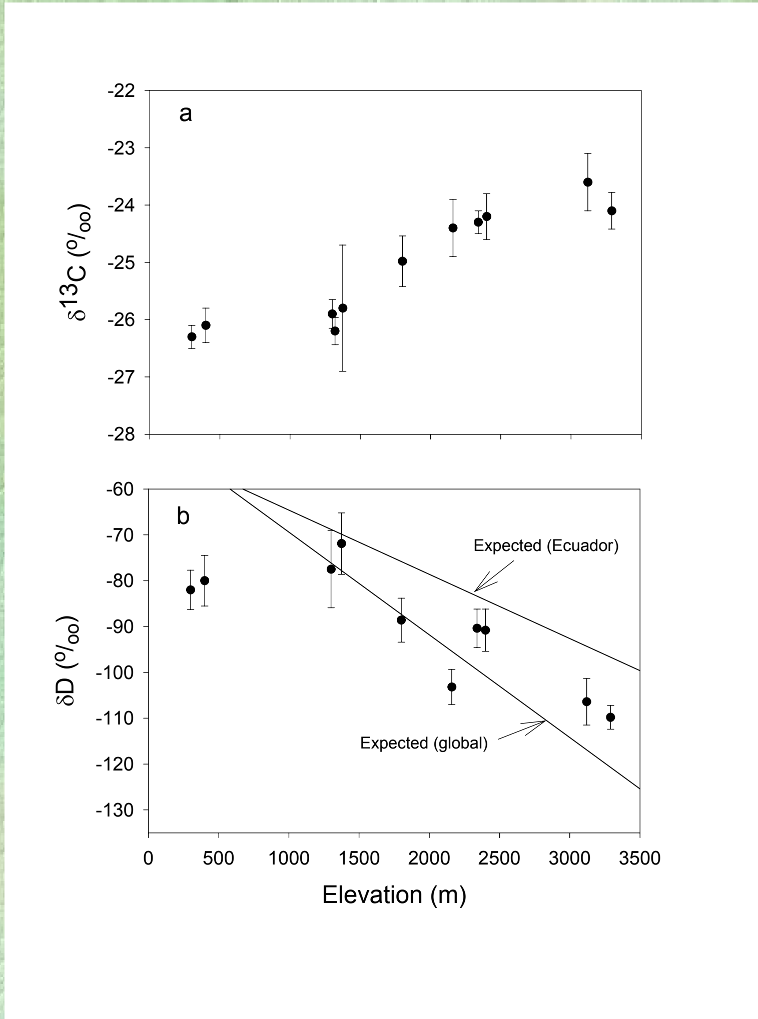
Kelly et al. (Oecologia 2002)

Altitudinal gradients are recorded in hummingbird feathers:



Hobson et al. *Oecologia* 136:302-308

The feather isotopes follow large scale trajectories in precip δD



Ecuador:

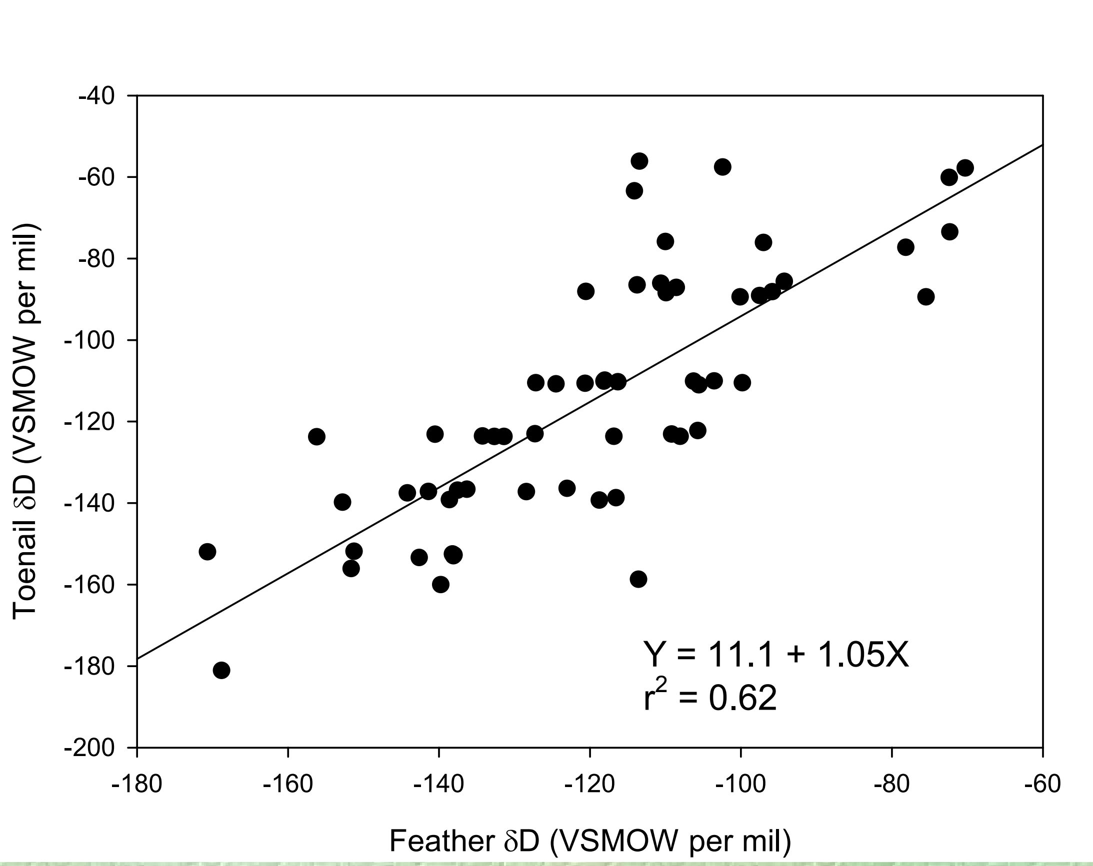
$\delta D_f = -25.6 + E(-0.014) -25\ ^o/oo$

Global:

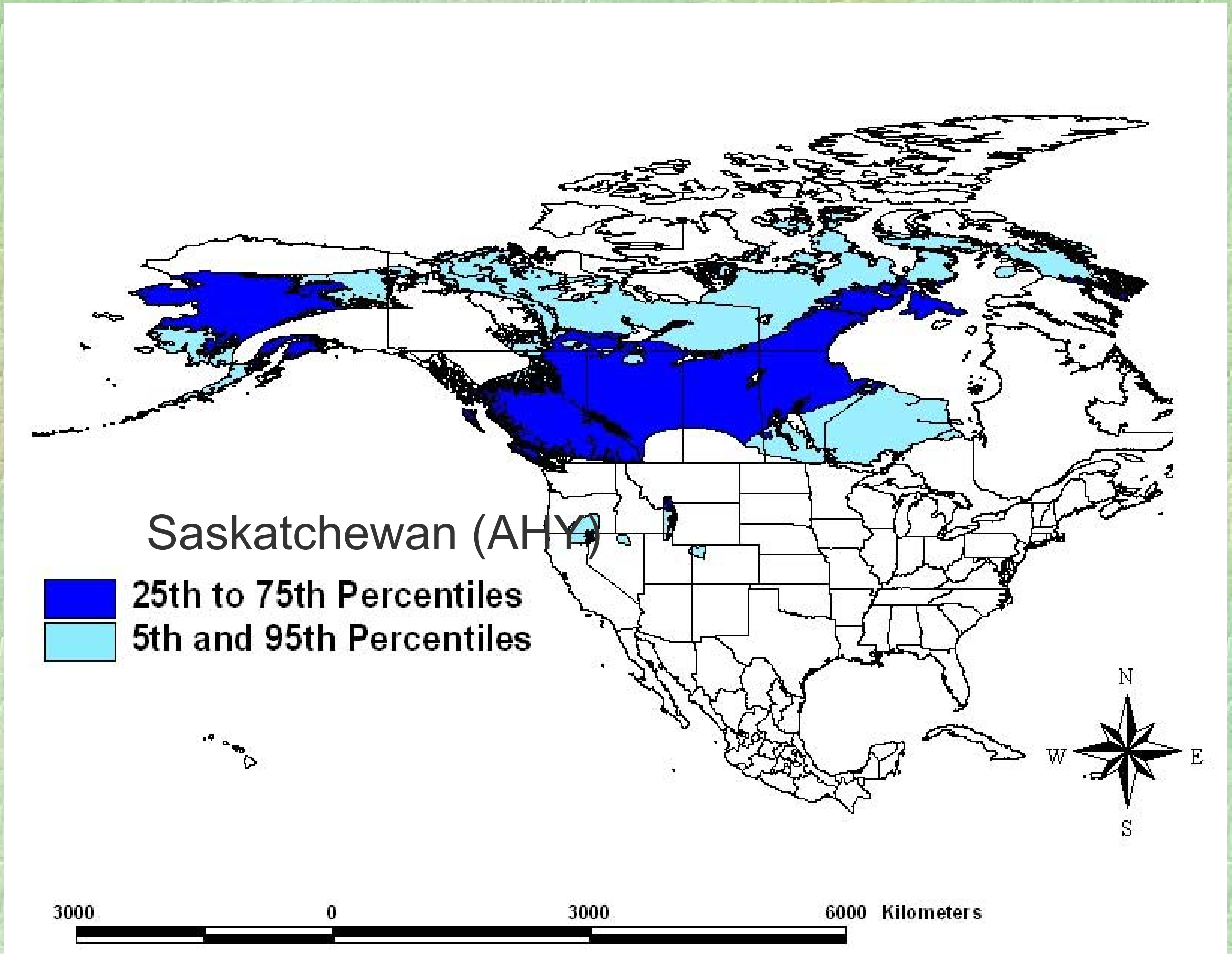
$\delta D_f = -22 + E(0.0224) -25\ ^o/oo$

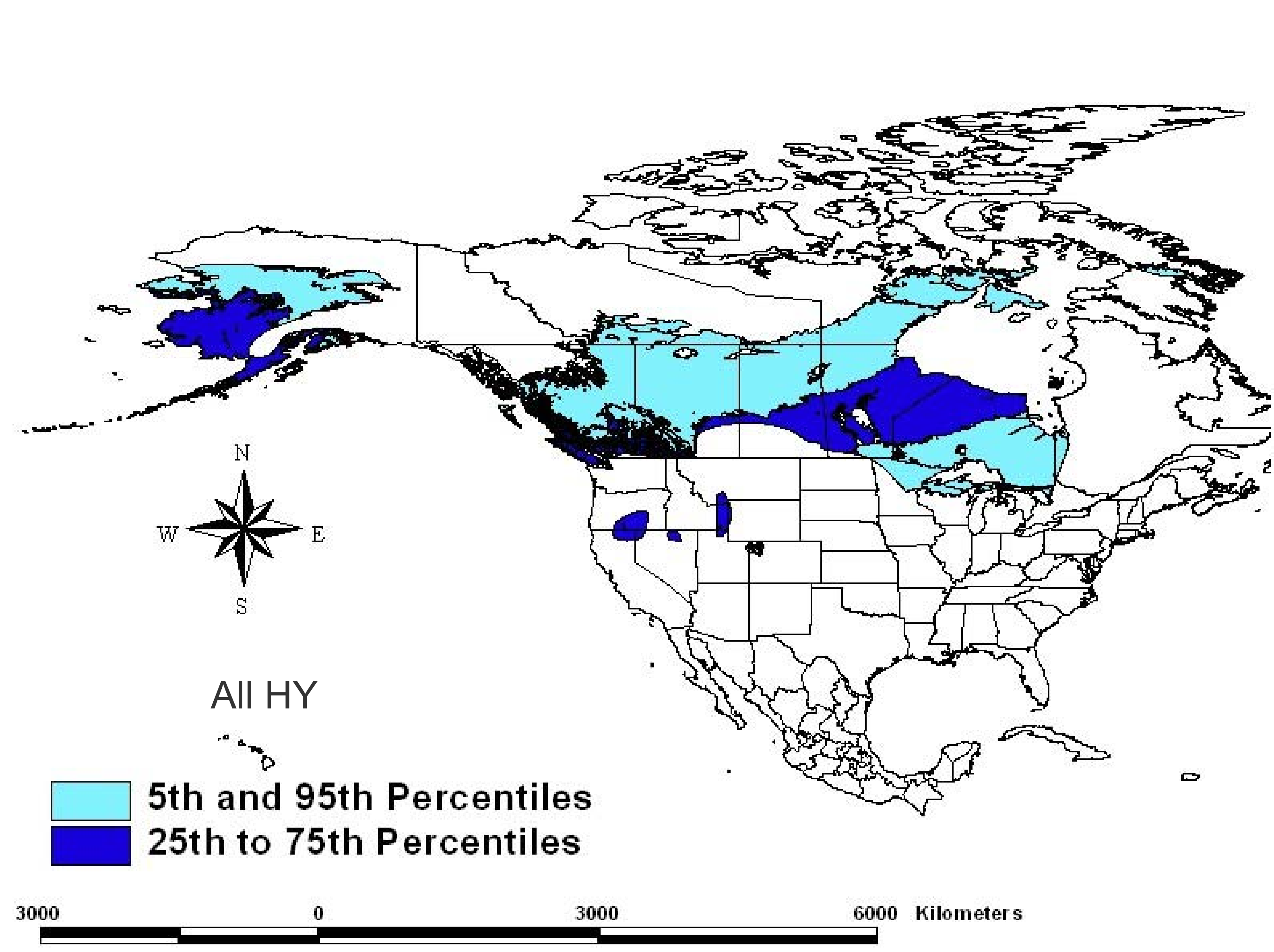
Origins of hunter-killed Sandhill Cranes?

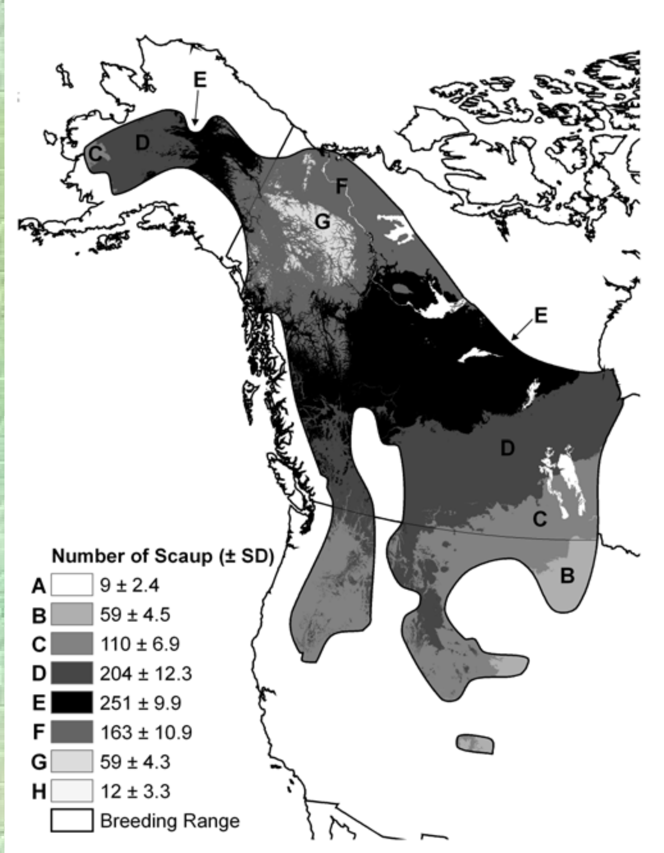
Toenails or feathers?



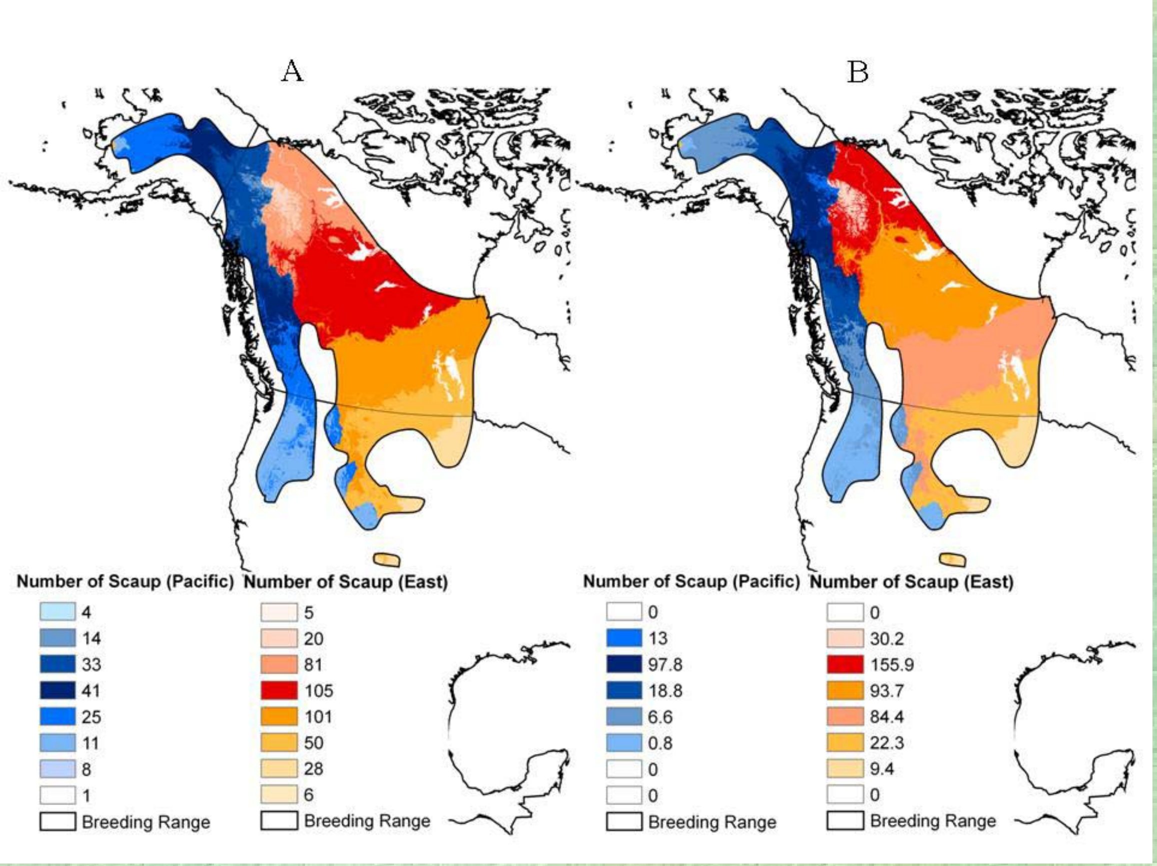
Combining isotope results with the isotope basemap GIS layer ….




All HY
N
W
E
S
5th and 95th Percentiles
25th to 75th Percentiles
3000
0
3000
6000
Kilometers

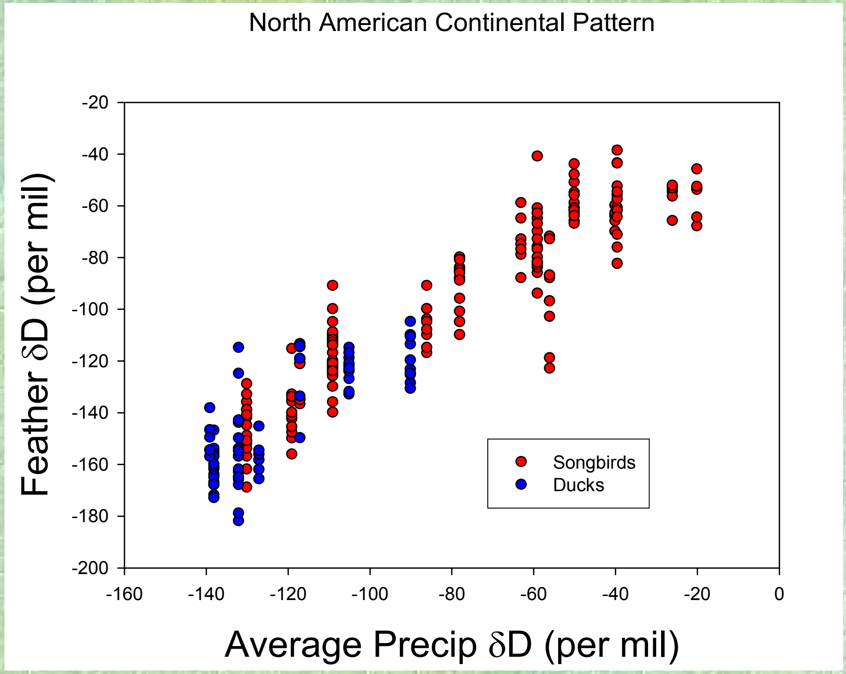


E
C
D
F
G
E
D
C
B
Number of Scaup (± SD)
A 9 ± 2.4
B 59 ± 4.5
C 110 ± 6.9
D 204 ± 12.3
E 251 ± 9.9
F 163 ± 10.9
G 59 ± 4.3
H 12 ± 3.3
Breeding Range

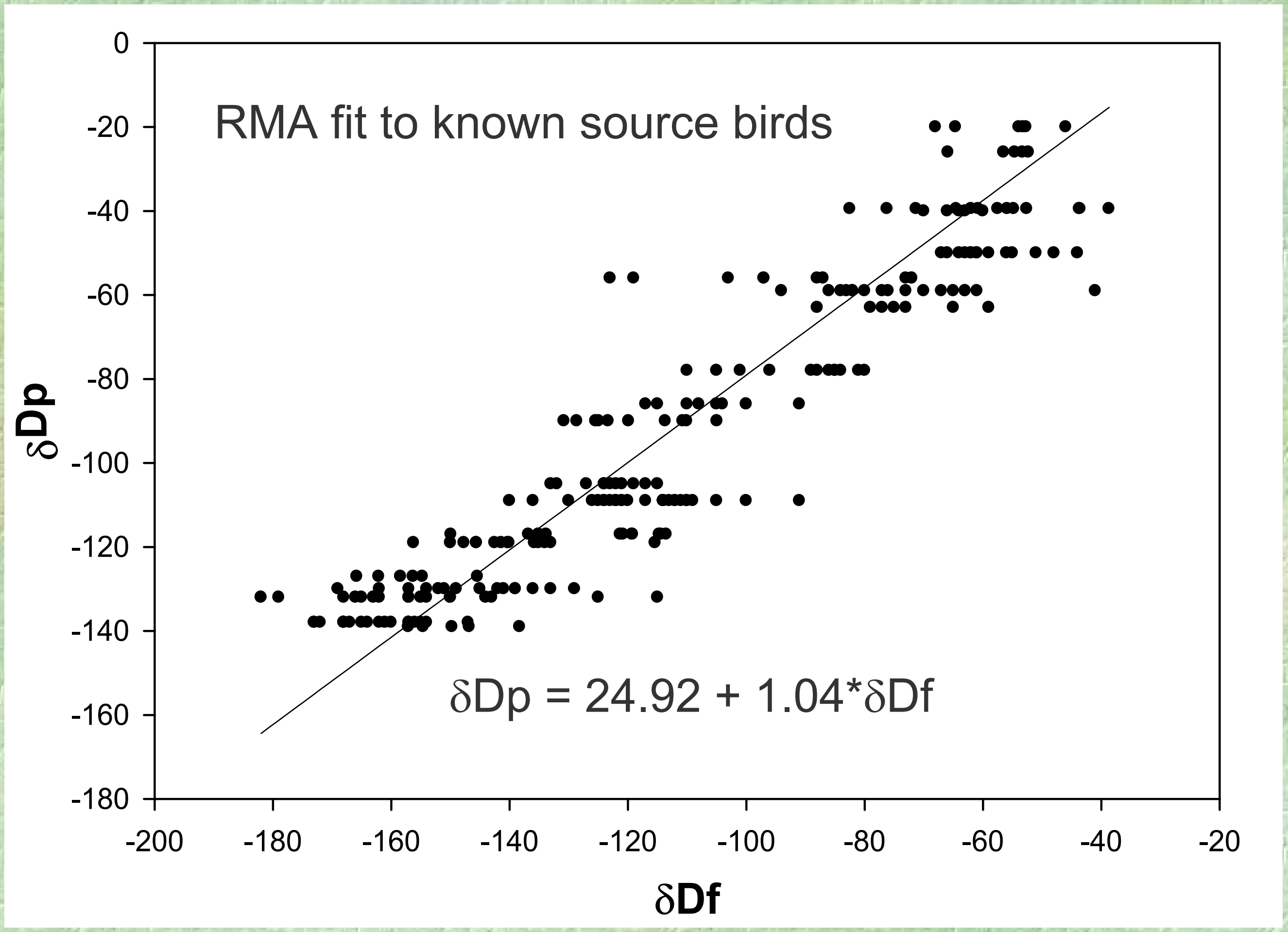

A
B
Number of Scaup (Pacific)
4
14
33
41
25
11
8
1
Breeding Range
Number of Scaup (East)
5
20
81
105
101
50
28
6
Breeding Range
Number of Scaup (Pacific)
0
13
97.8
18.8
6.6
0.8
0
0
Breeding Range
Number of Scaup (East)
0
30.2
155.9
93.7
84.4
22.3
9.4
0
Breeding Range

Moving beyond the "map lookup" approach …..

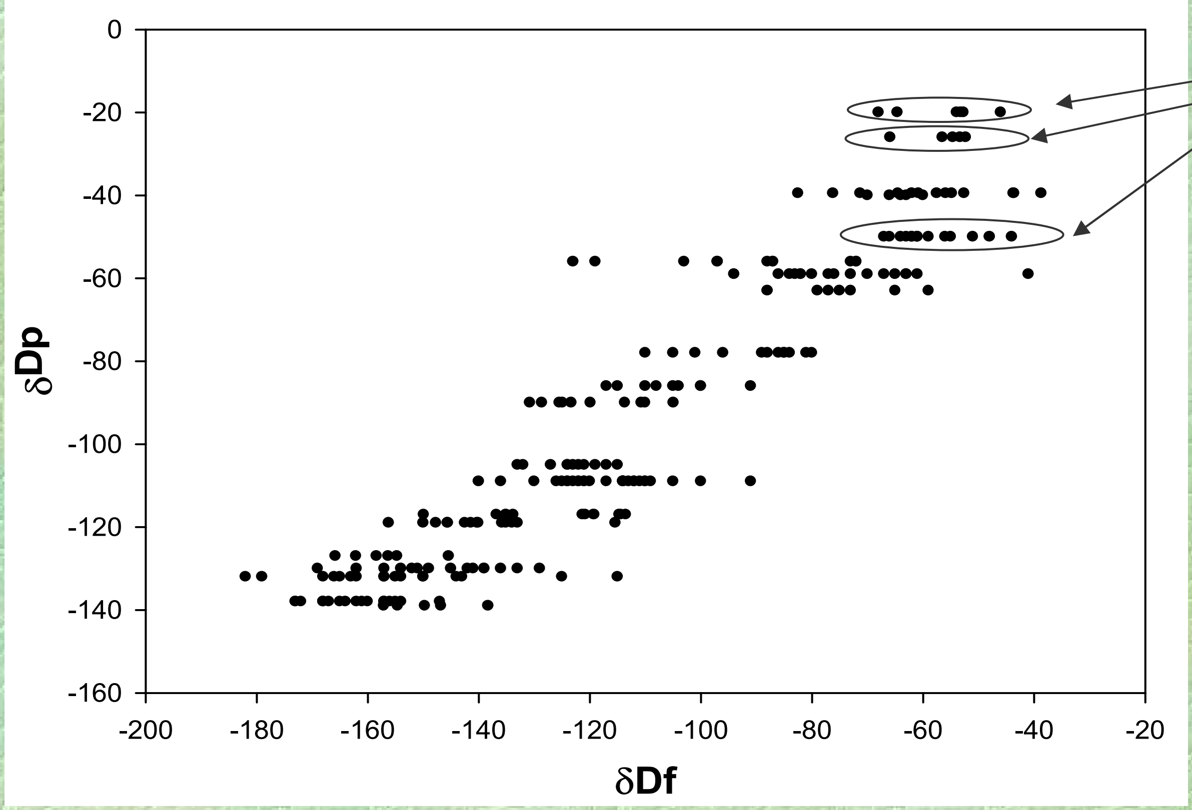
- Propagate error associated with analytical measurement and geospatial models of δDp.



Converting to δDp units



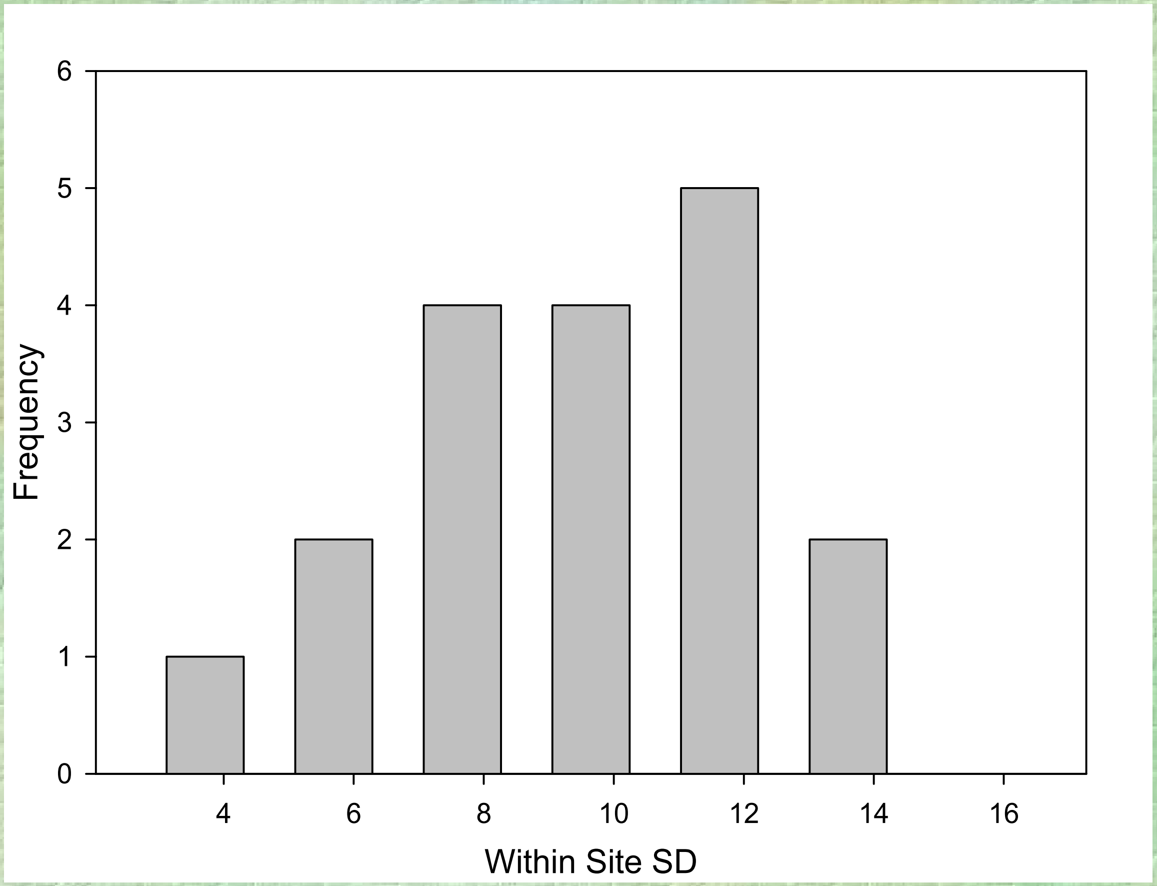
Within Site "Errors"



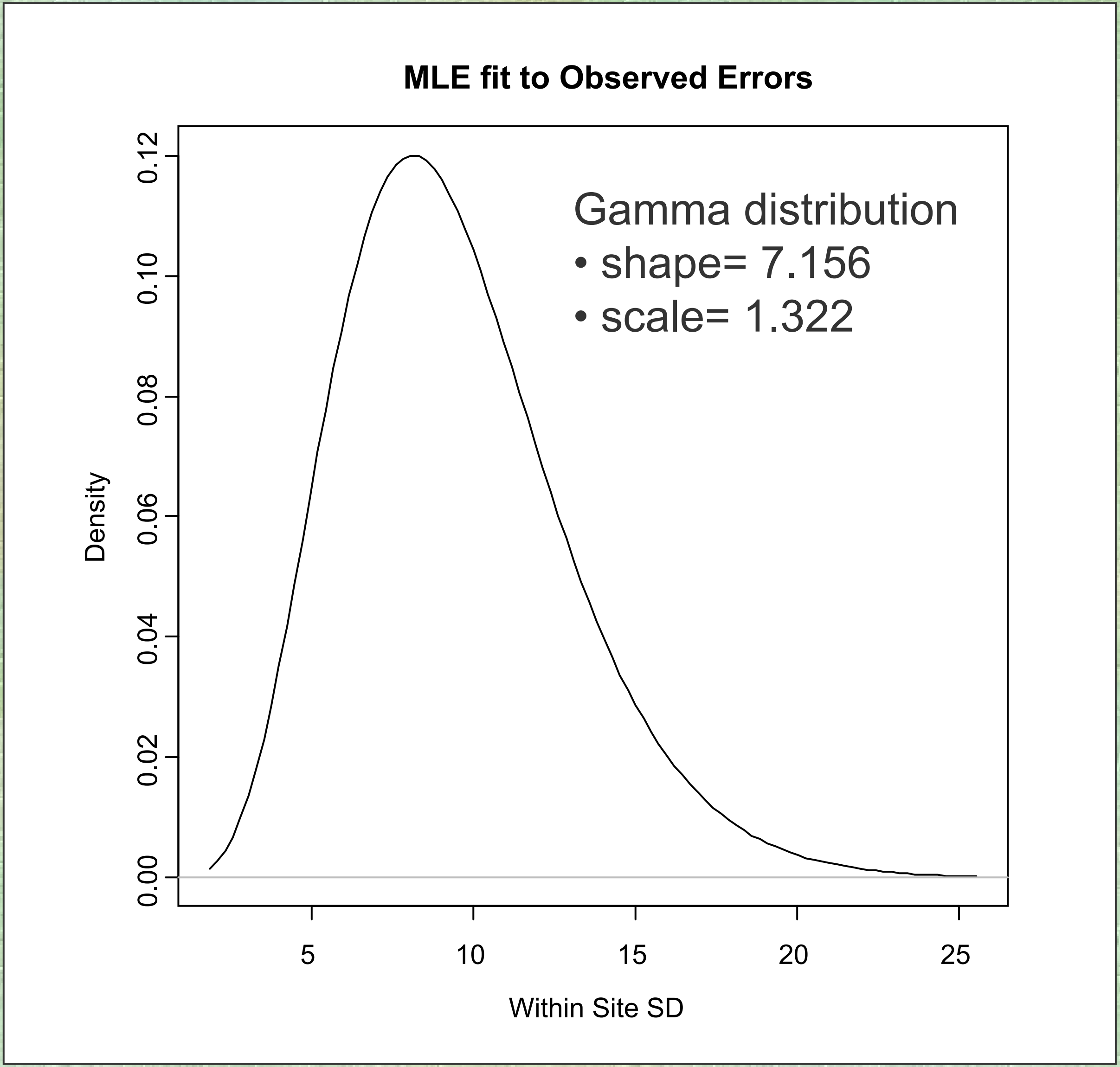
Calculate SD for each Site

Incorporates:
- analytical error
- individual heterogeneity

Observed Distribution of errors



Fit distribution to errors

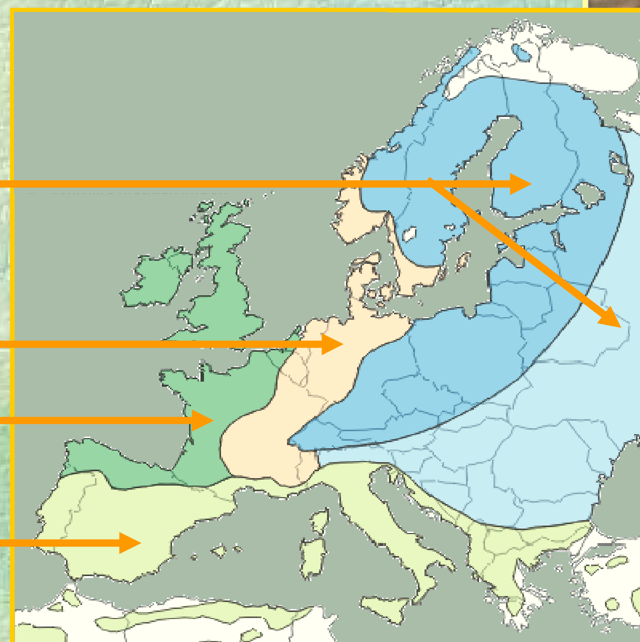


Propagate errors (simulation)

- 1000 simulations per measured δD_f (in δD_p units)
- Where:
  - Mean = measured δD_p equivalent value of feather
  - SD drawn at random from estimated error distribution

Origins of Woodpigeons killed in France

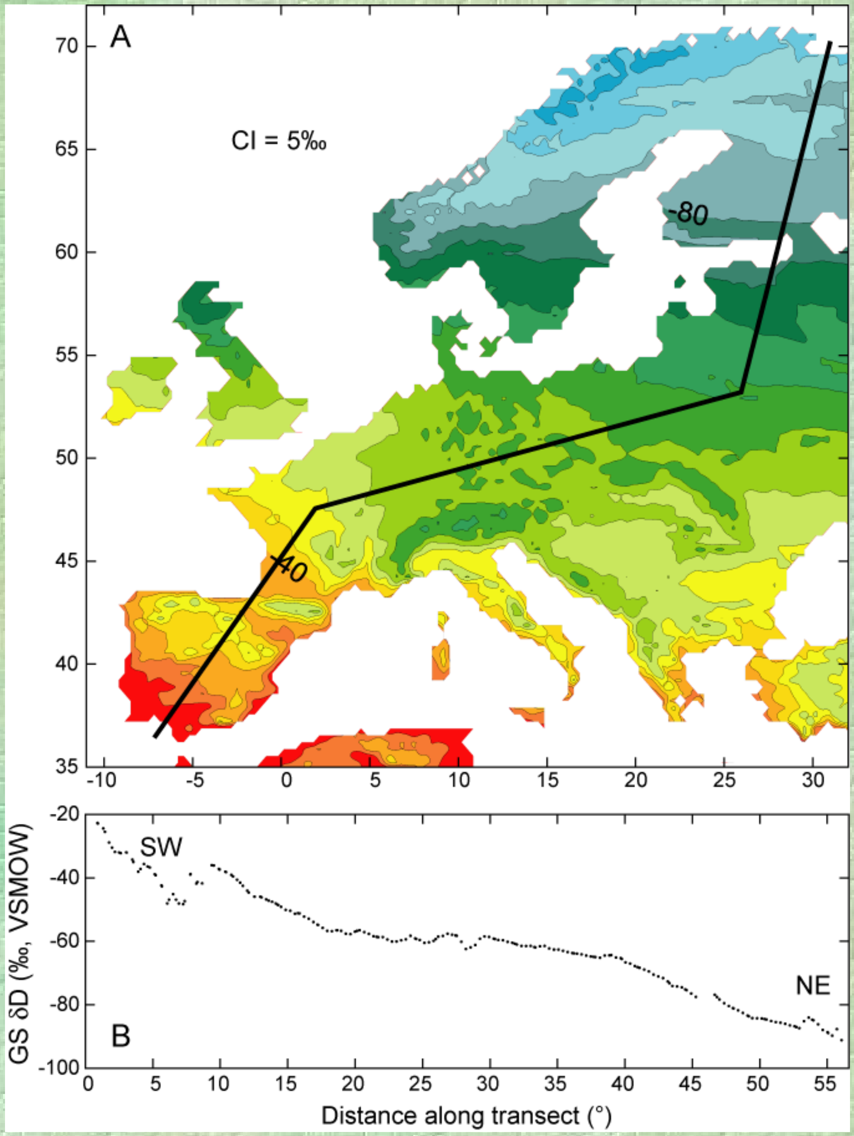
Several distinct populations with specific migratory traits



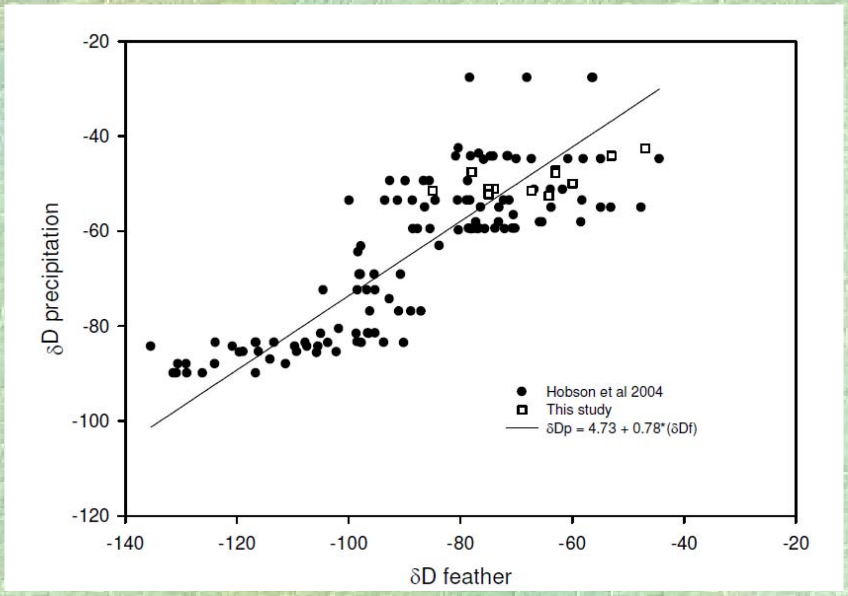
Long-range migrant (winter in southern range of Europe)

Medium-range migrant (winter in France)

sedentary

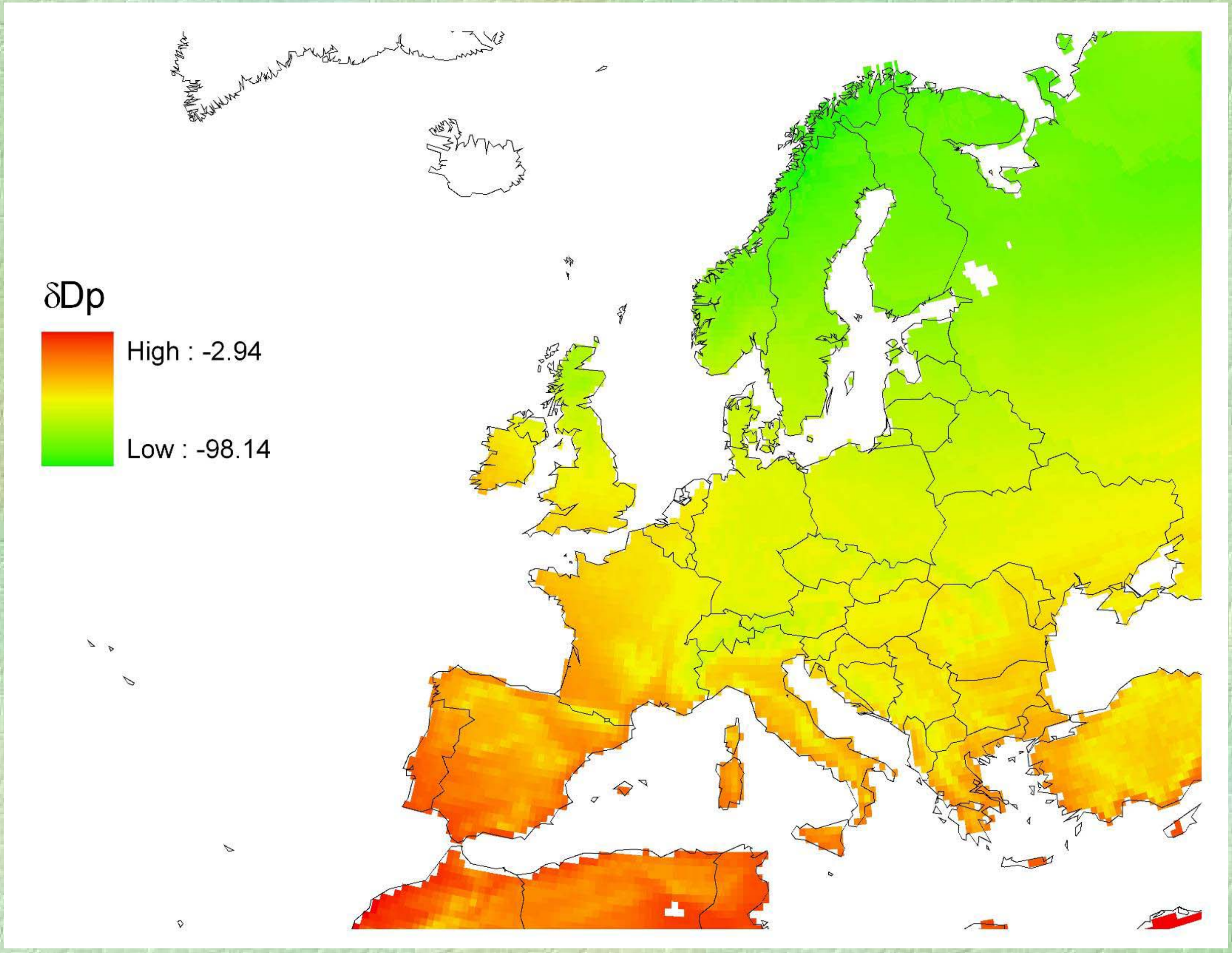


A
CI = 5‰
-80
-40
B
SW
NE
GS δD (‰, VSMOW)
Distance along transect (°)

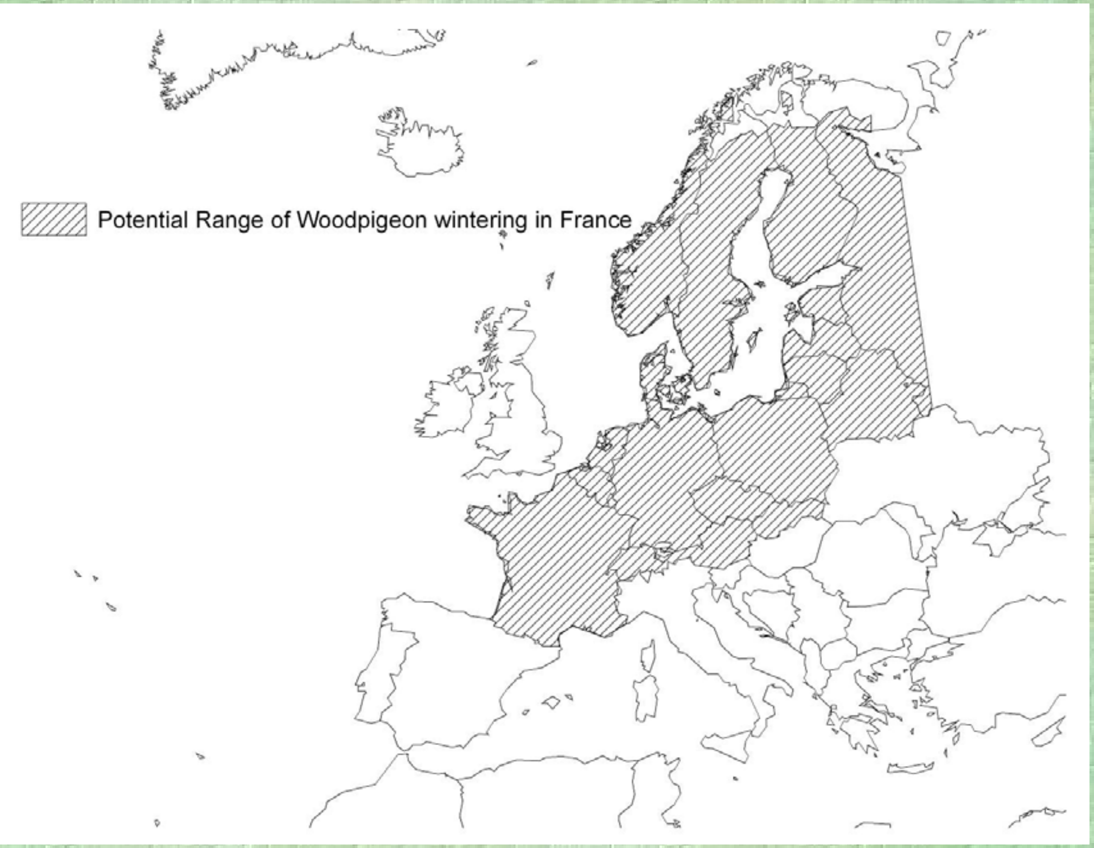


δD precipitation
δD feather
Hobson et al 2004
This study
δDp = 4.73 + 0.78*(δDf)

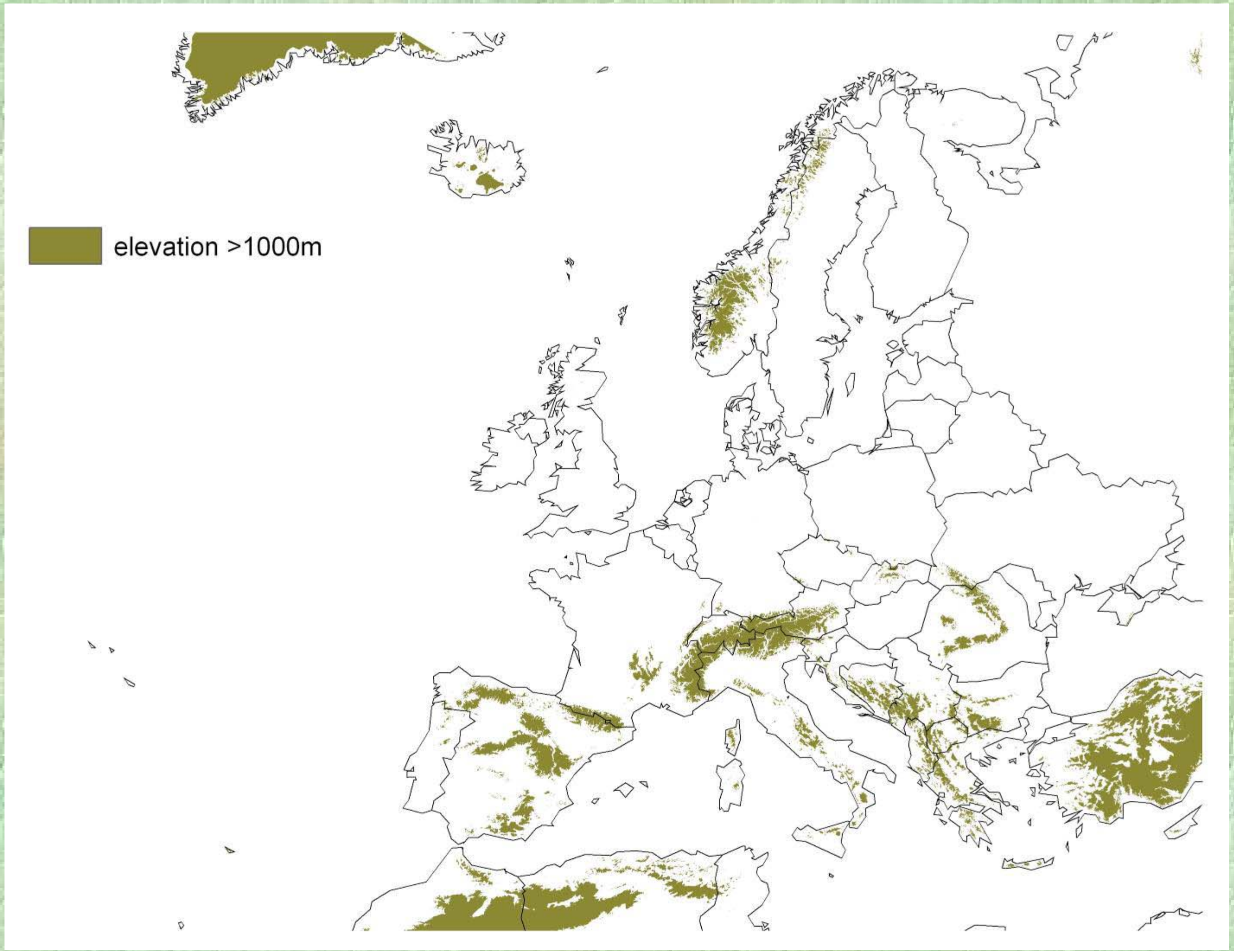
Constraining Origins



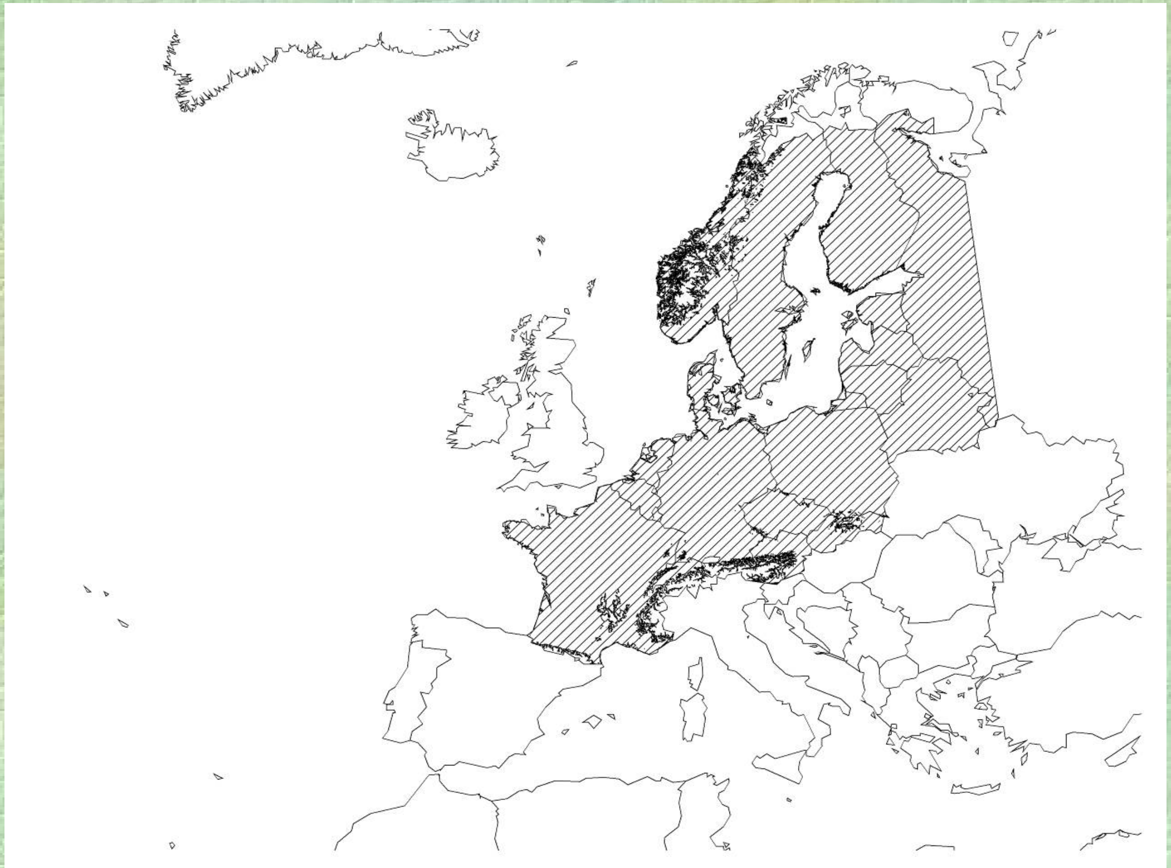
Constraining to Potential Range



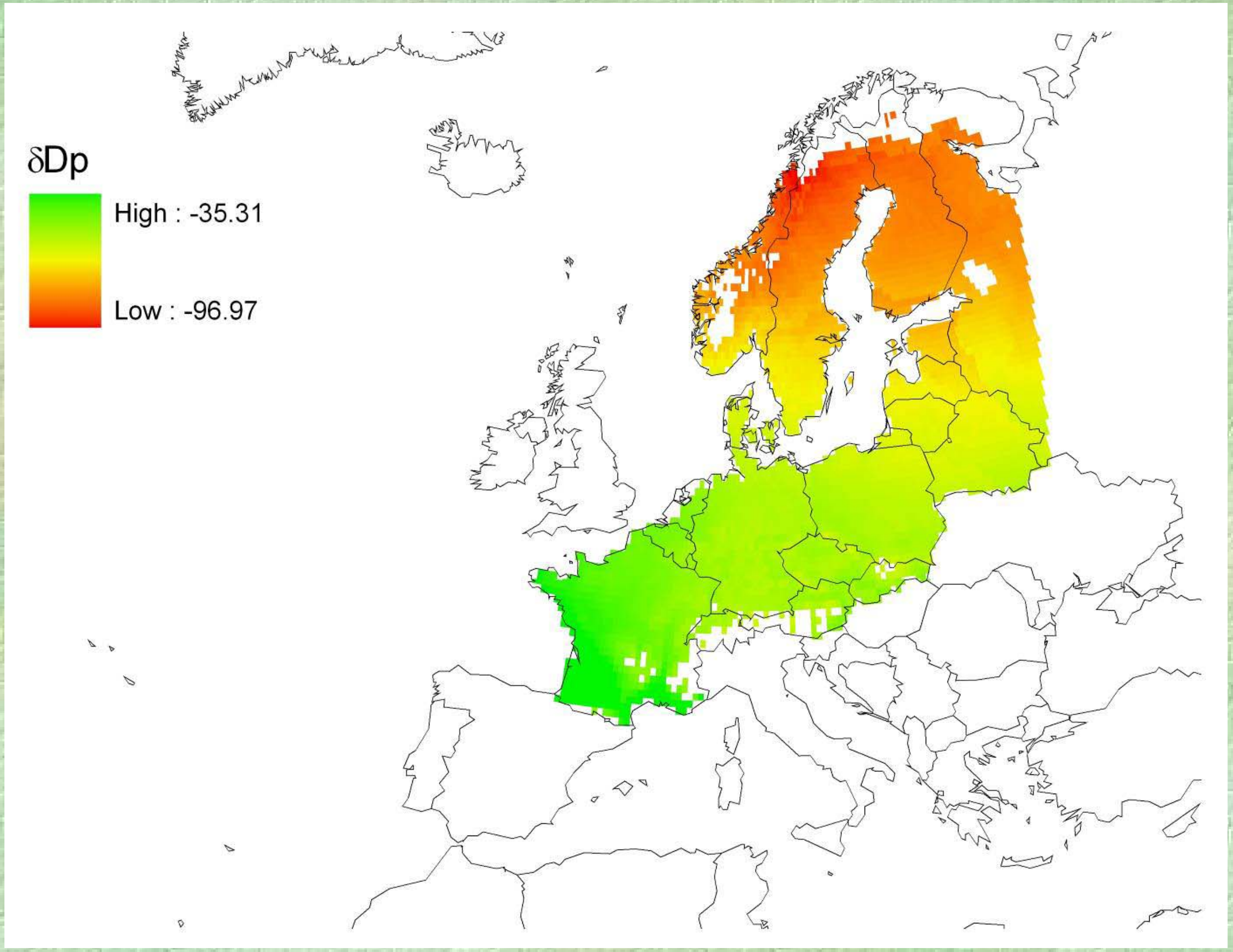
Constraint- Elevation



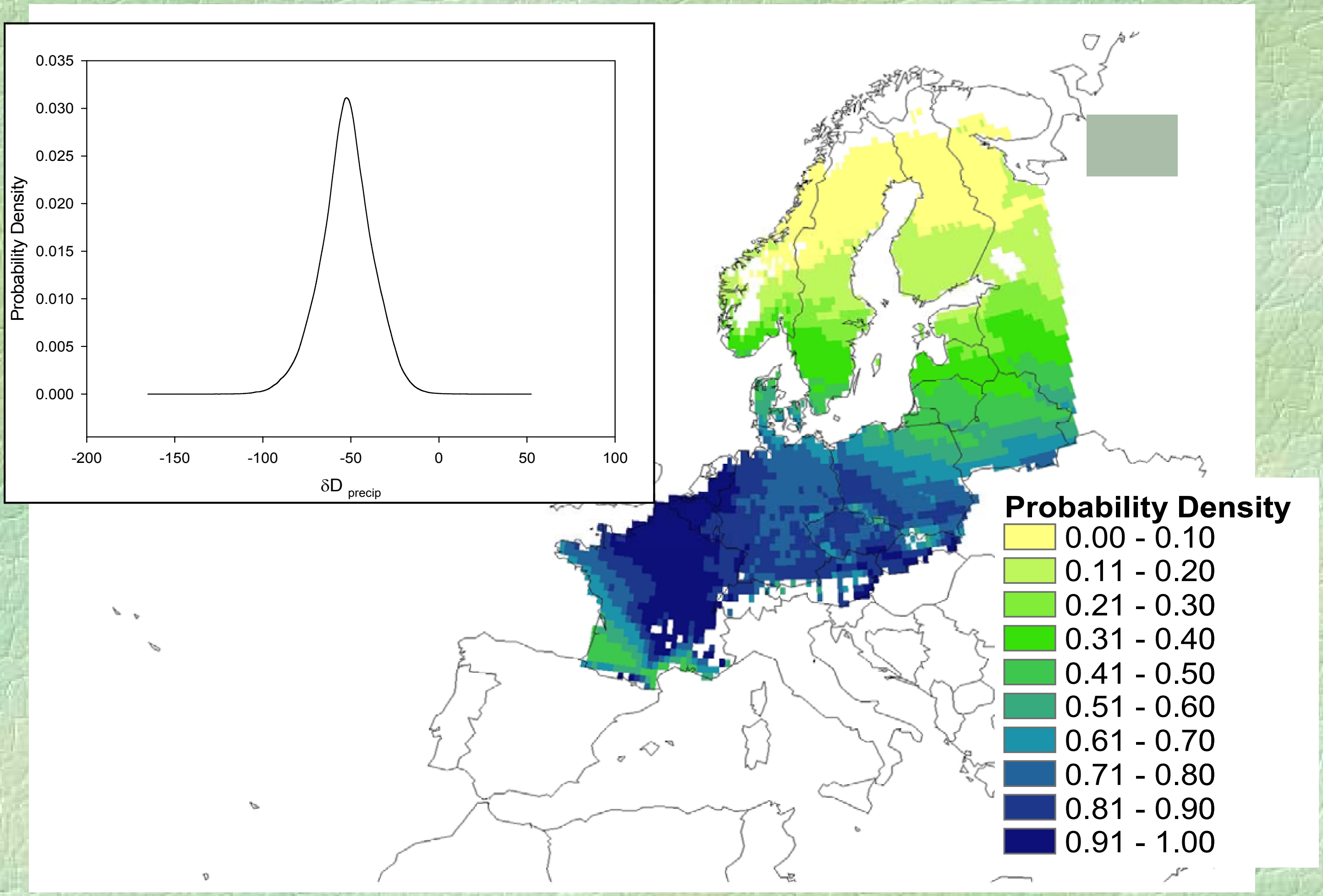
Reduced solution space- remove high elevation

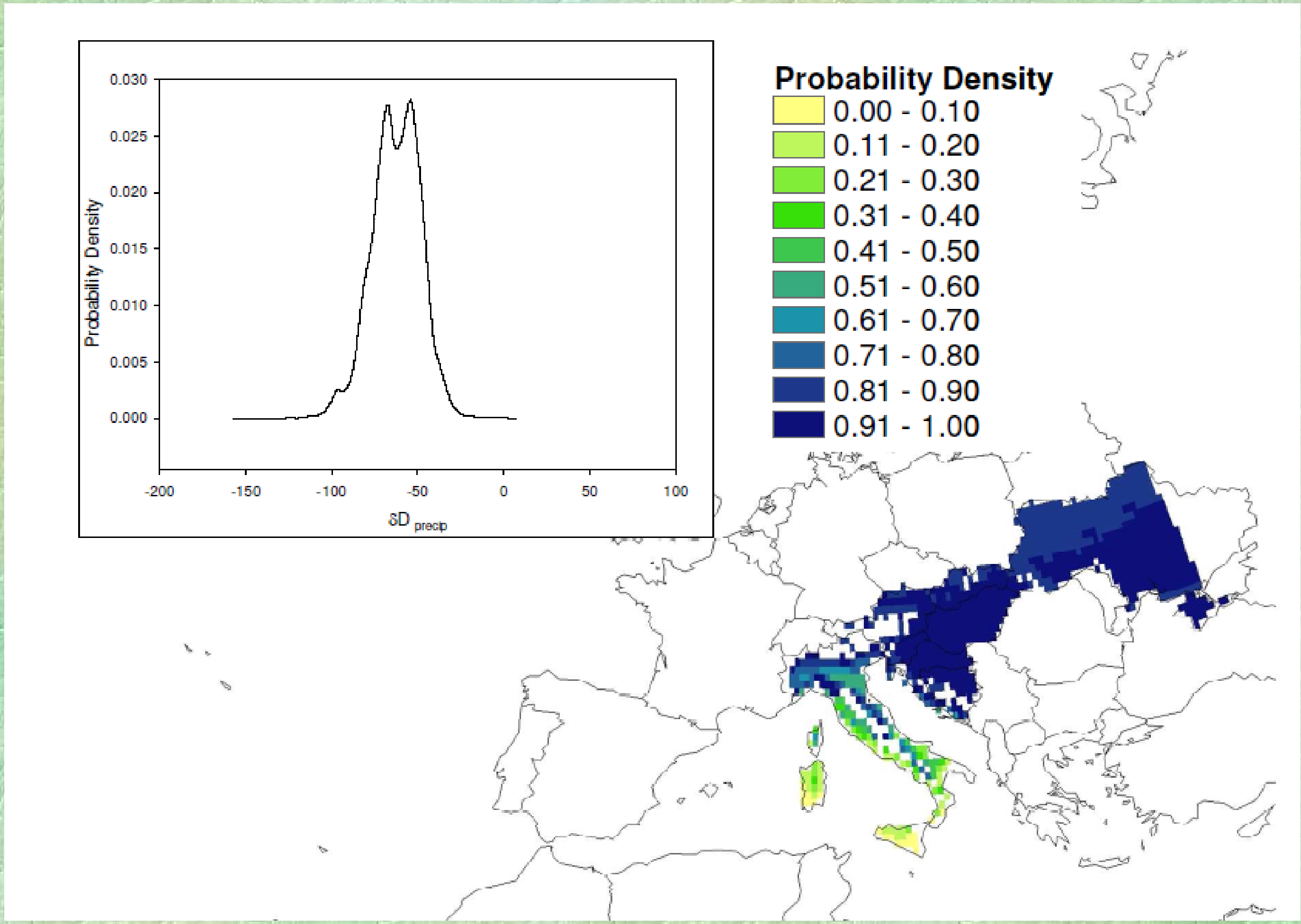


GSD- for reduced range

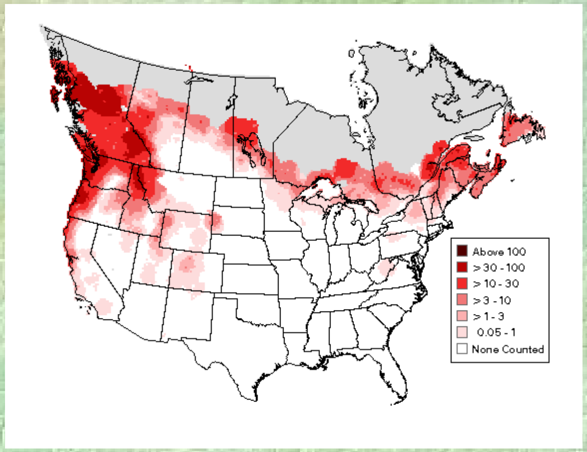


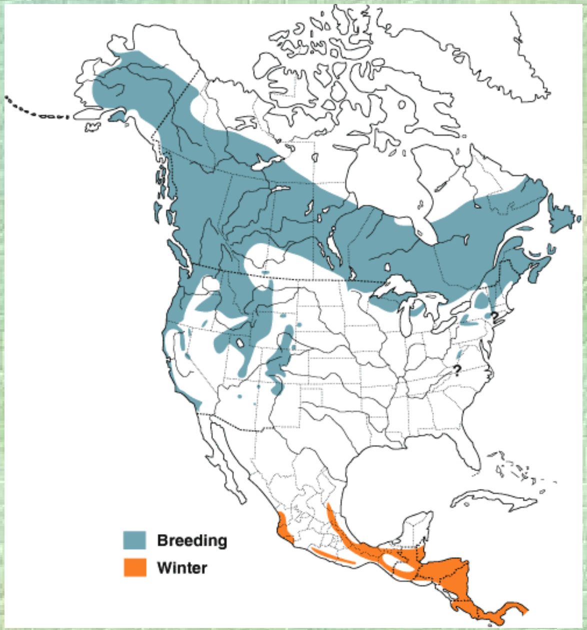
Assignment of Origins

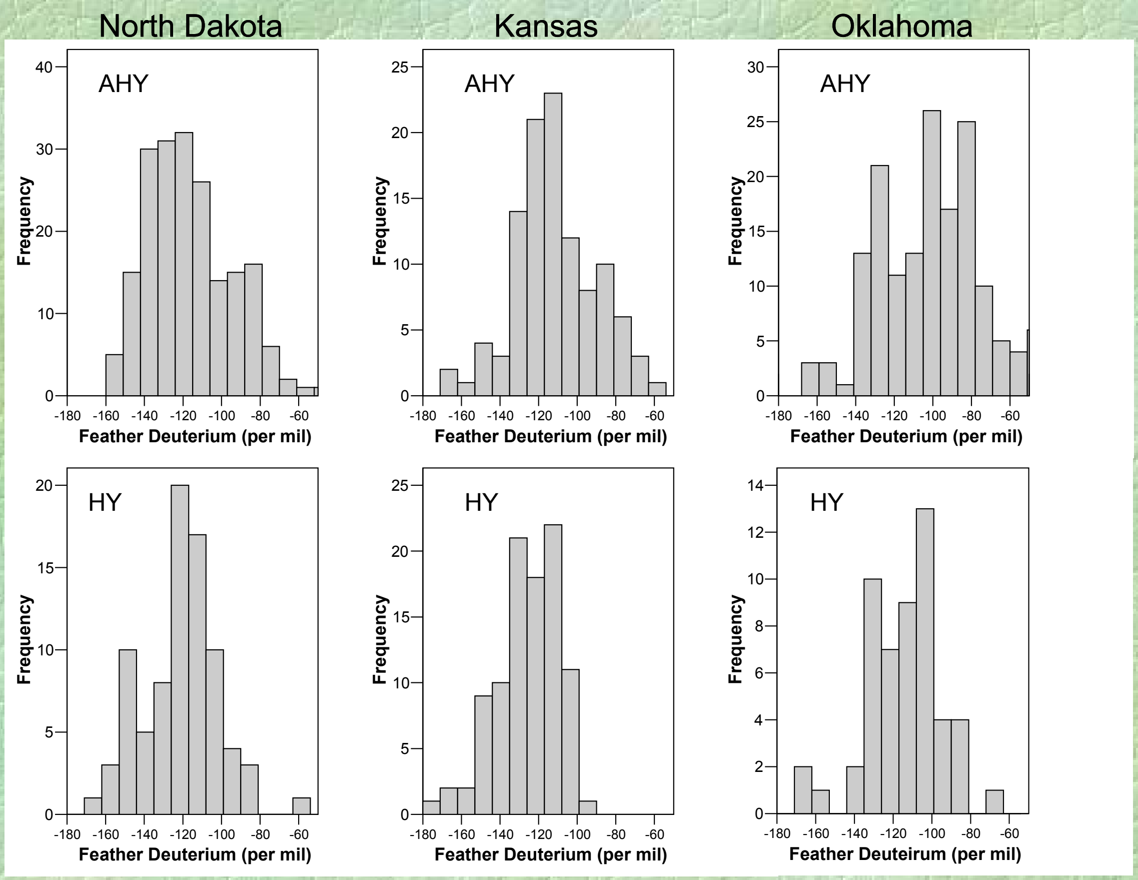



0.030
0.025
0.020
0.015
0.010
0.005
0.000
Probability Density
-200
-150
-100
-50
0
50
100
δD precip
Probability Density
0.00 - 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
0.51 - 0.60
0.61 - 0.70
0.71 - 0.80
0.81 - 0.90
0.91 - 1.00

Limitations of the BBS for Boreal Birds

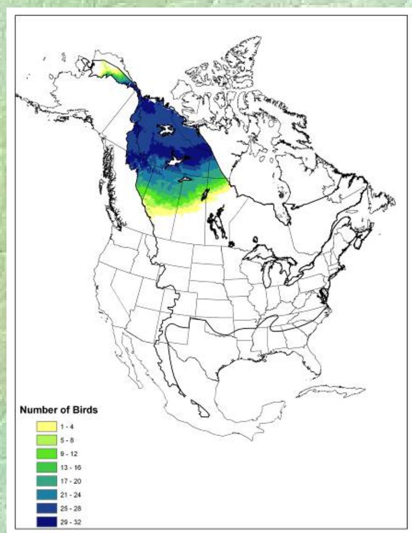




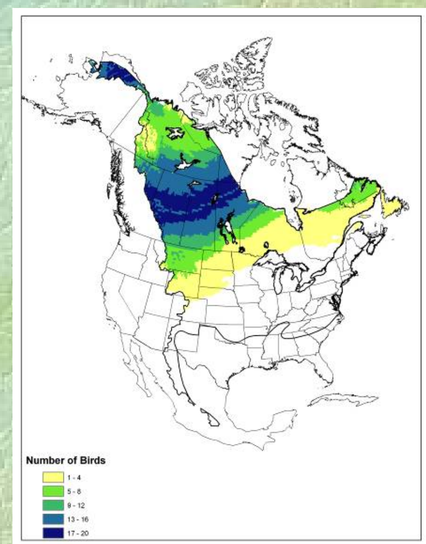

North Dakota
Kansas
Oklahoma
AHY
HY
Frequency
Feather Deuterium (per mil)
Feather Deuteirum (per mil)
-180 -160 -140 -120 -100 -80 -60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

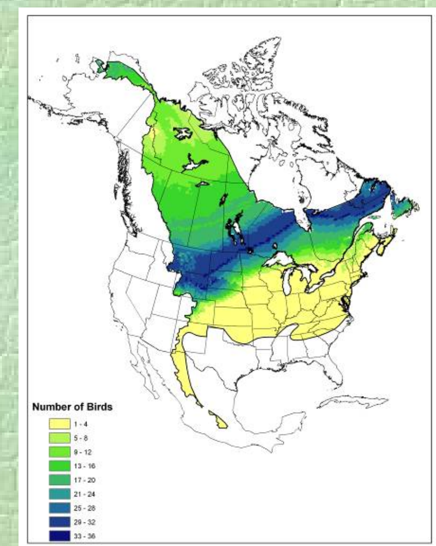
Yellow Warbler (Fall)



LMBO, BBO, LSLBO



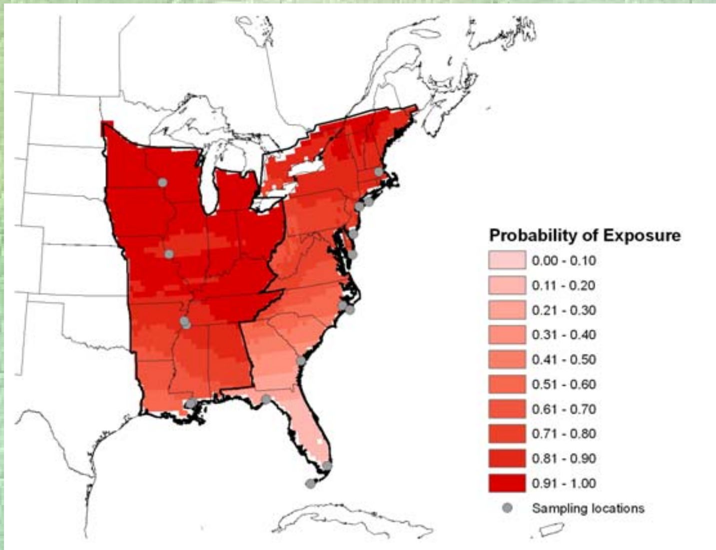
TCBO, DMBO



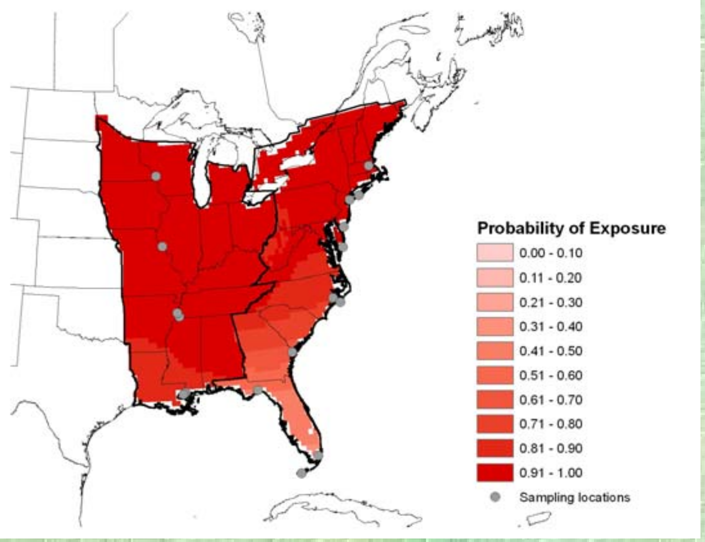
Maritimes, Quebec, Ont.

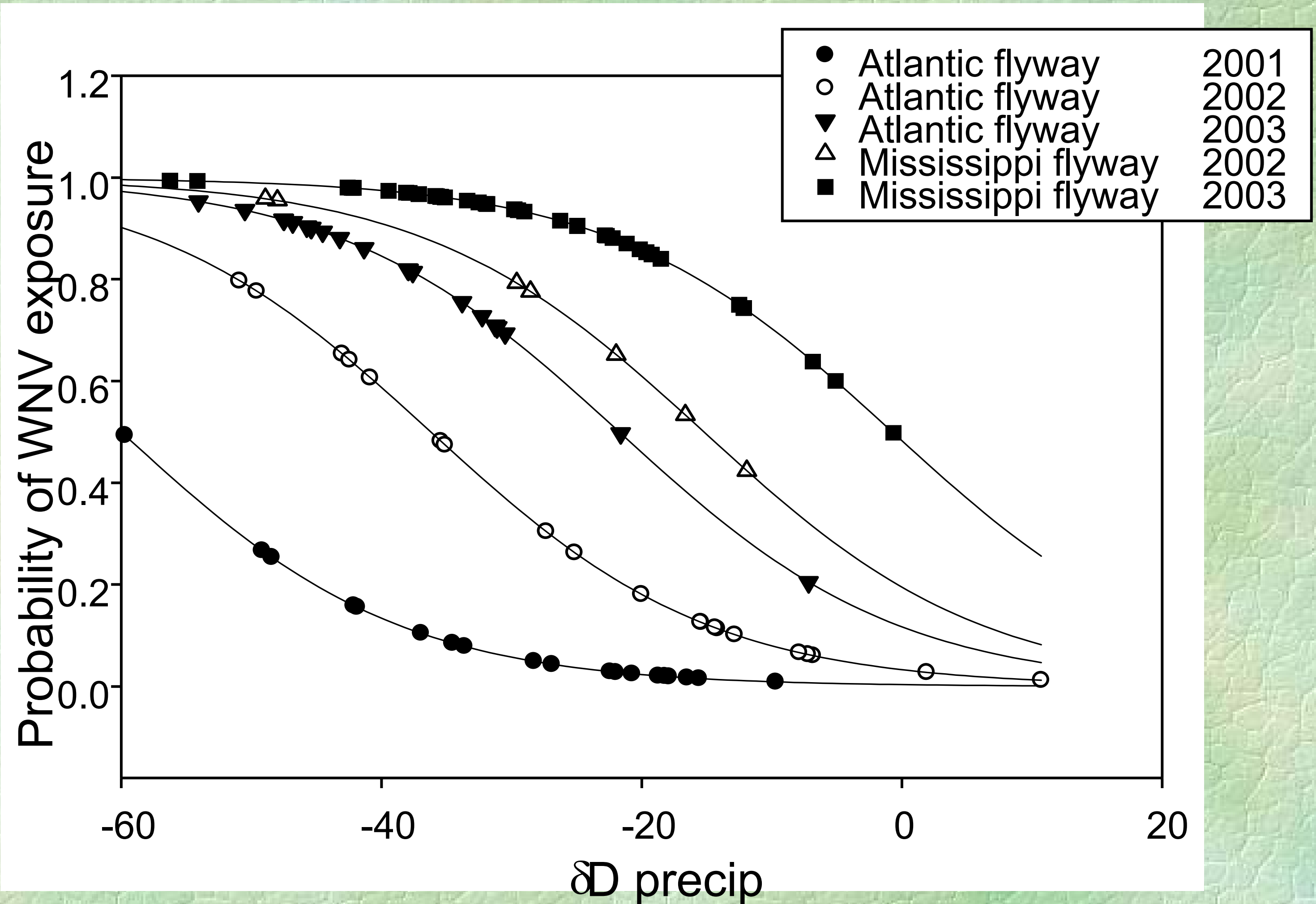
West Nile Virus exposure in N. Cardinals

2002



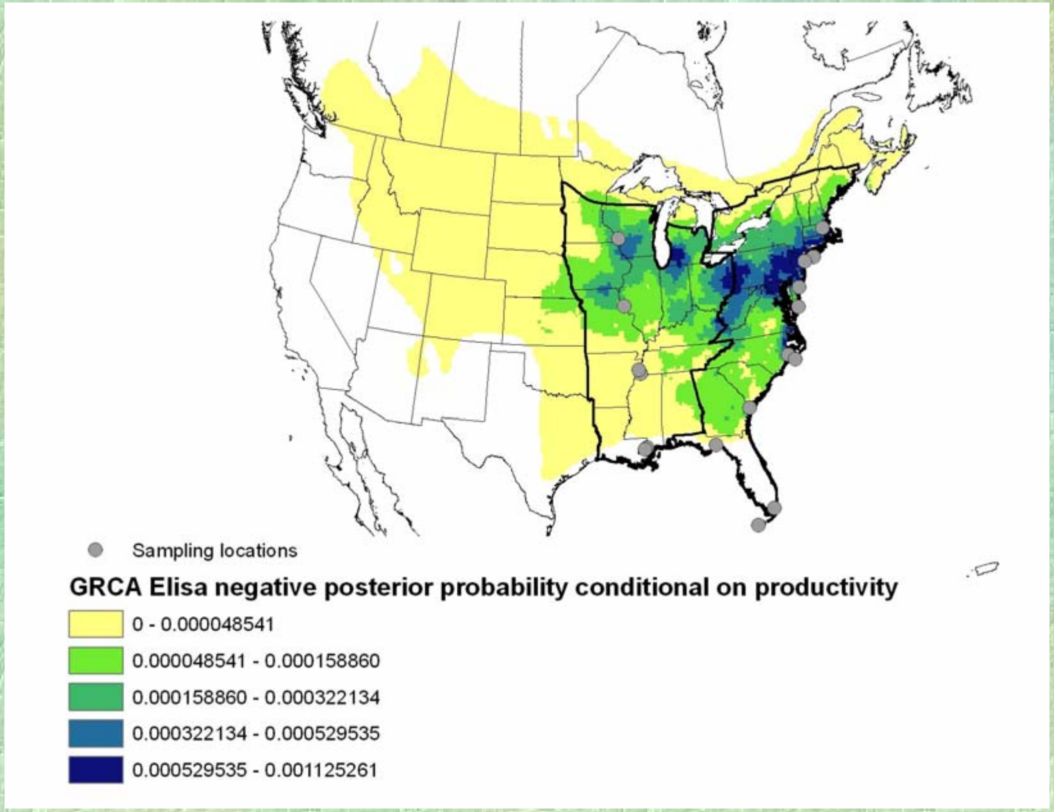
2003



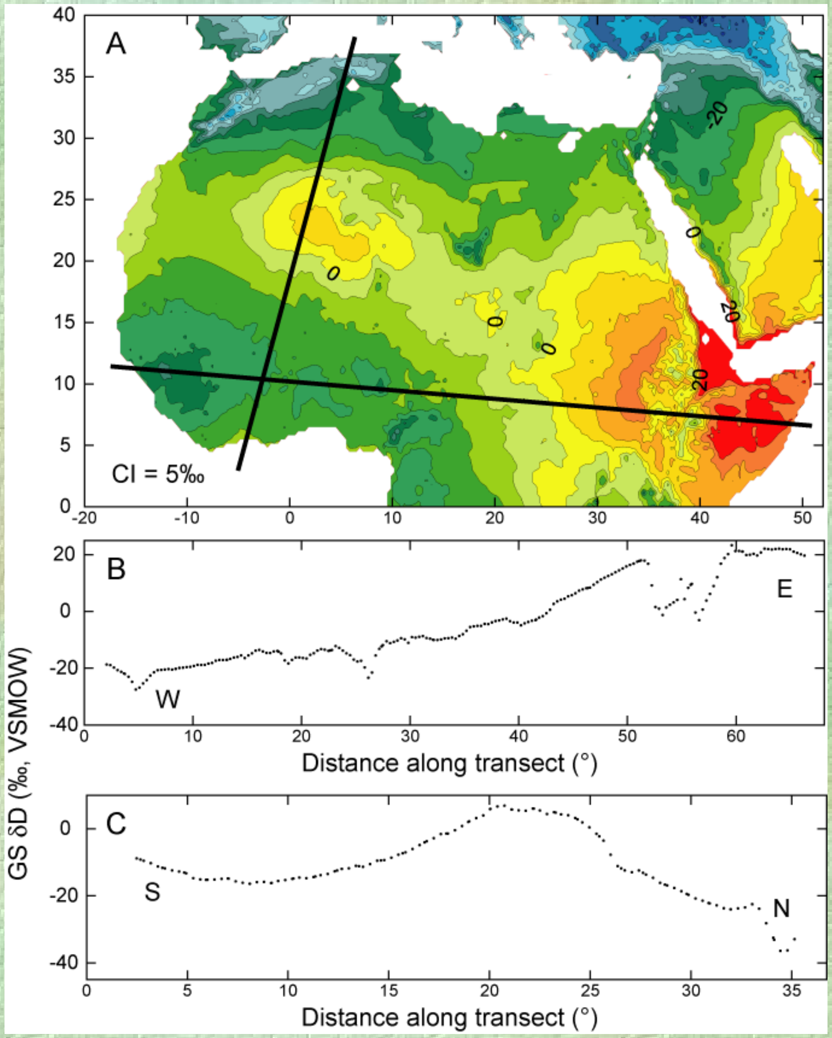


Atlantic flyway 2001
Atlantic flyway 2002
Atlantic flyway 2003
Mississippi flyway 2002
Mississippi flyway 2003
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Probability of WNV exposure
-60
-40
-20
0
20
δD precip

WNV in Gray Catbirds (2003)



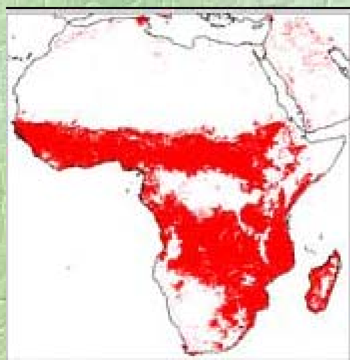
For North Africa …



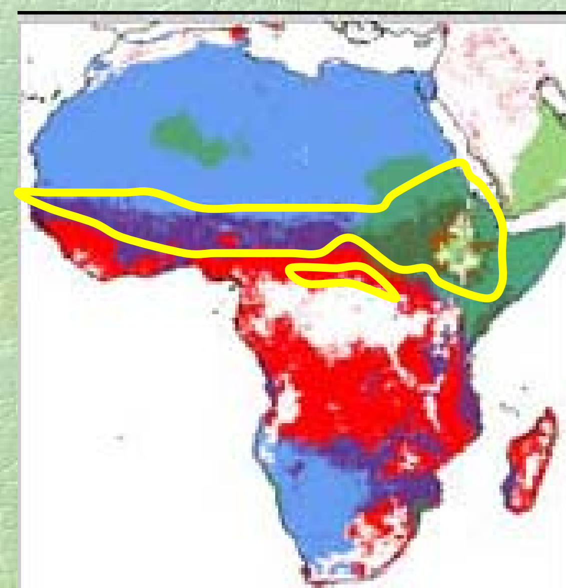
Bowen et al., 2005

3-dimensional isoscape for trans-Saharan migrants ….

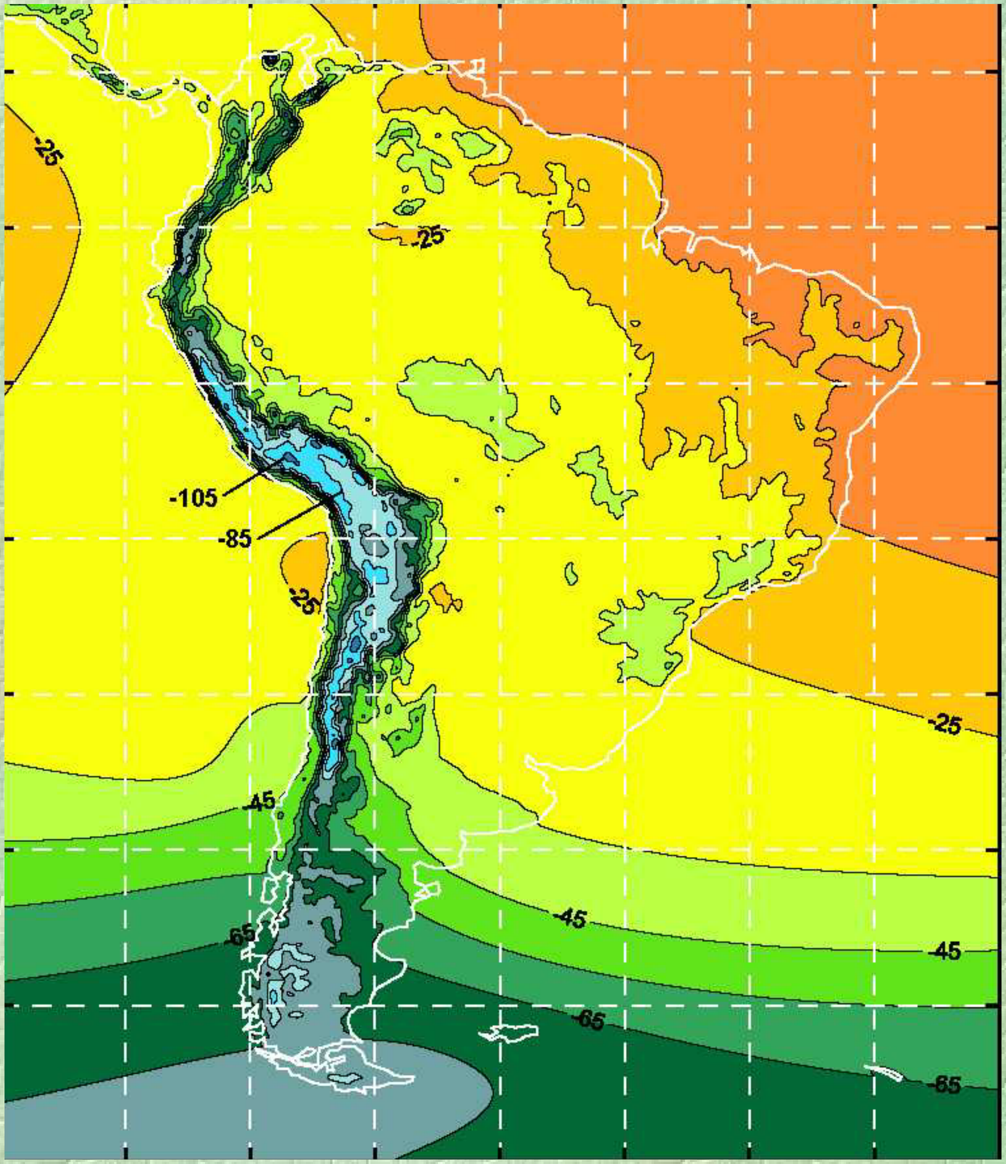
$\delta^{13}C$



δD

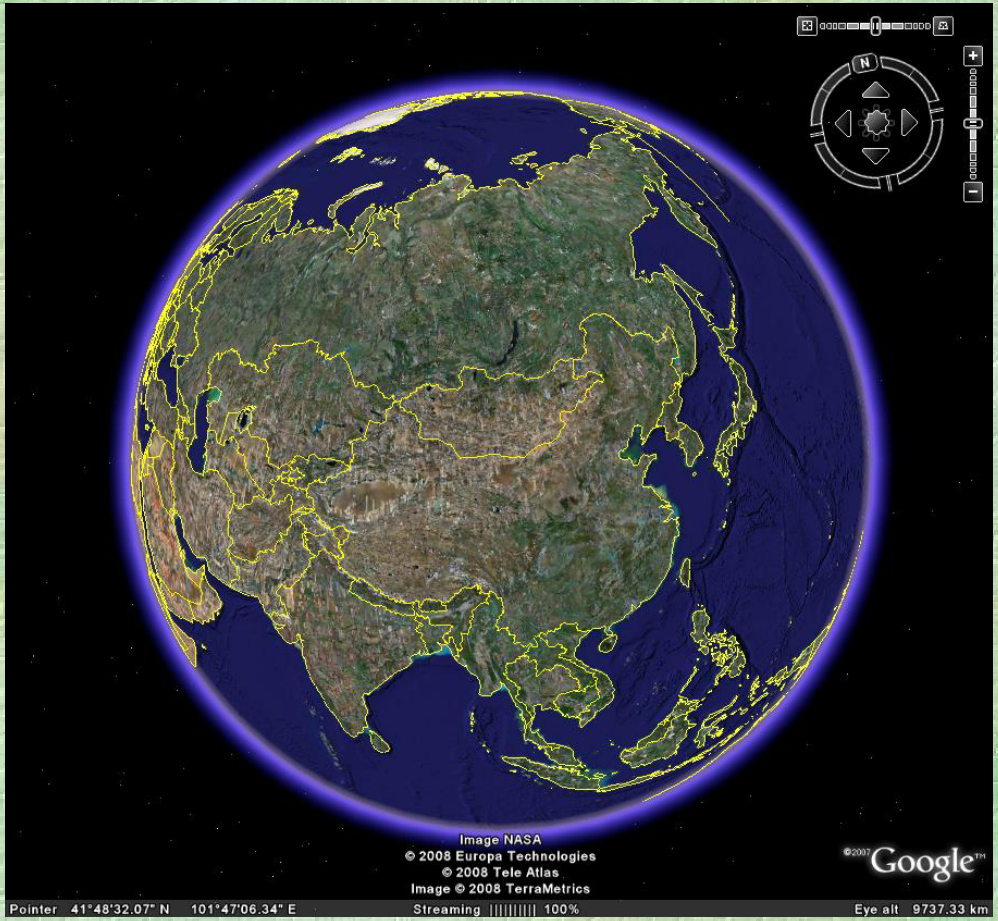


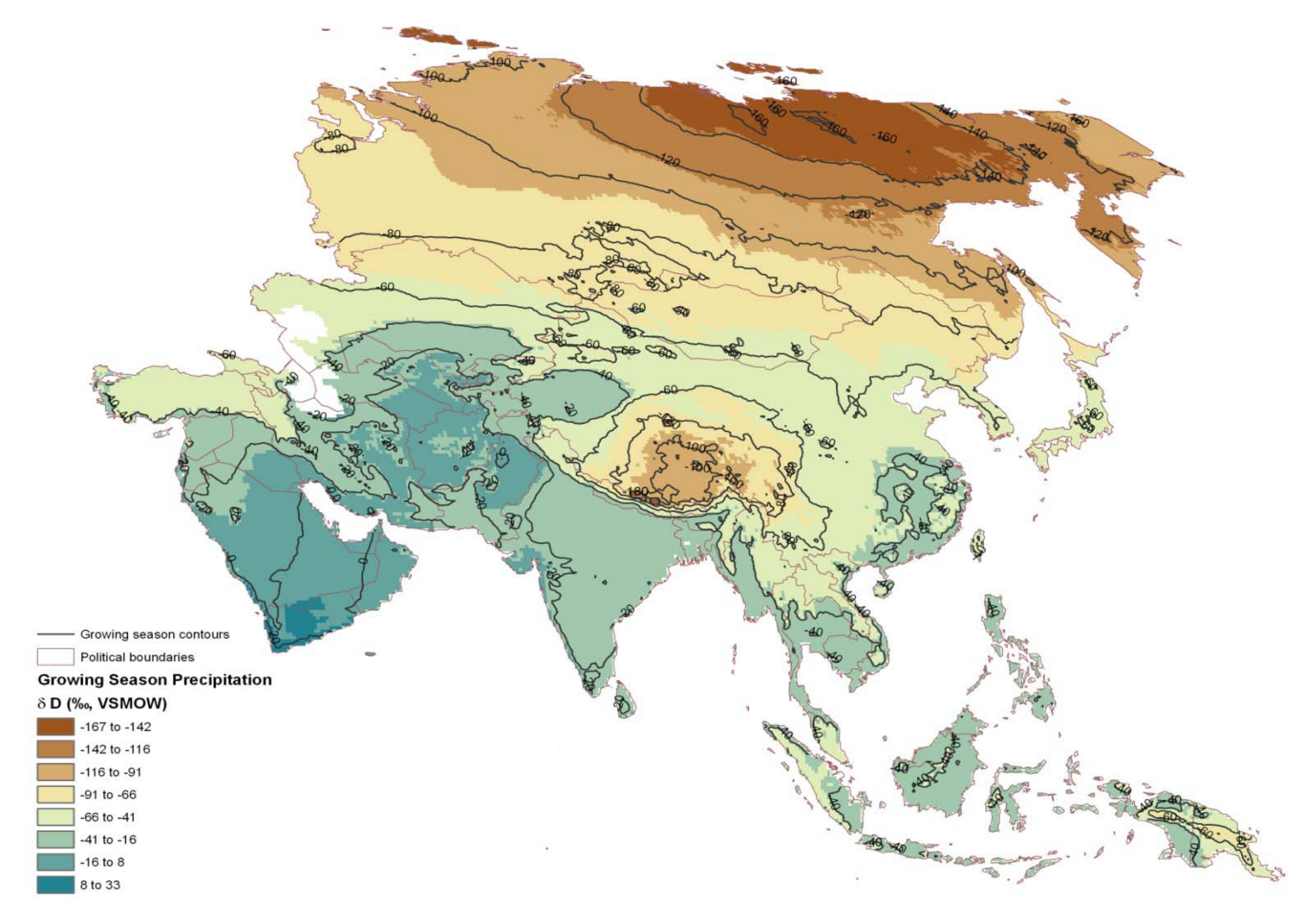
$\delta^{15}N$



Bowen, unpub.

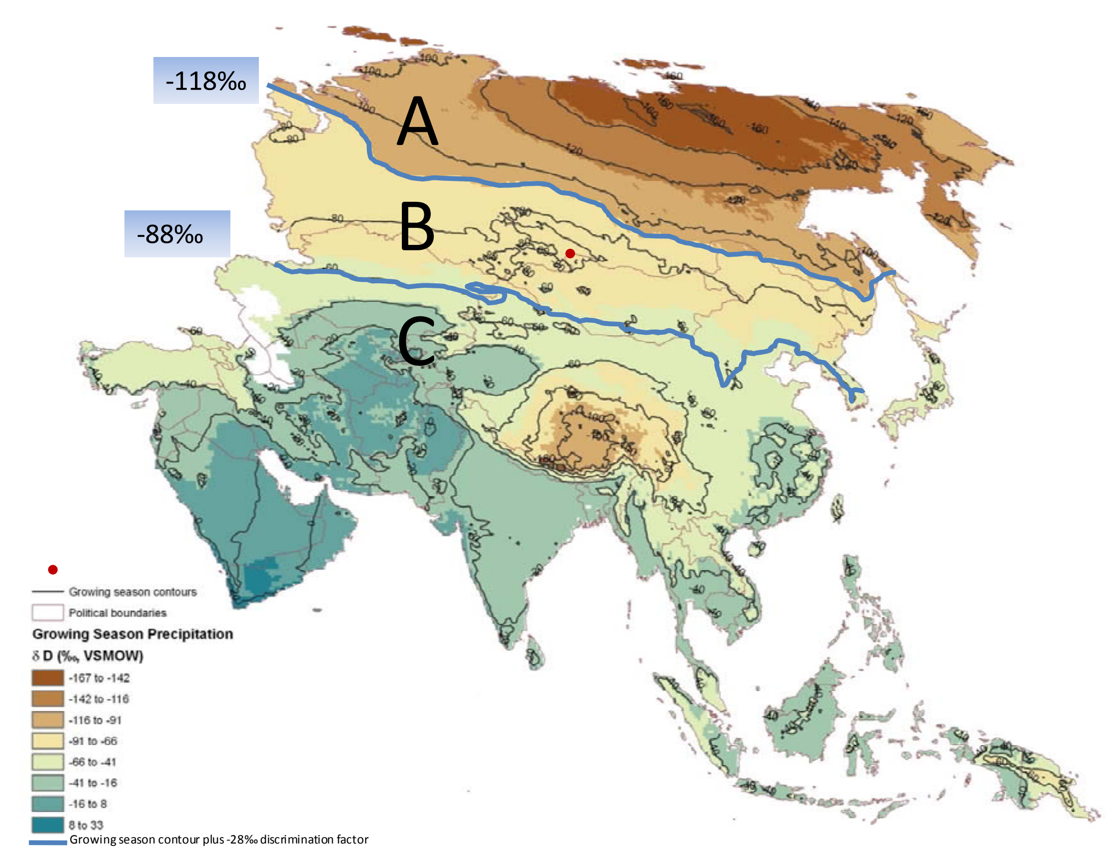
What about Asia?



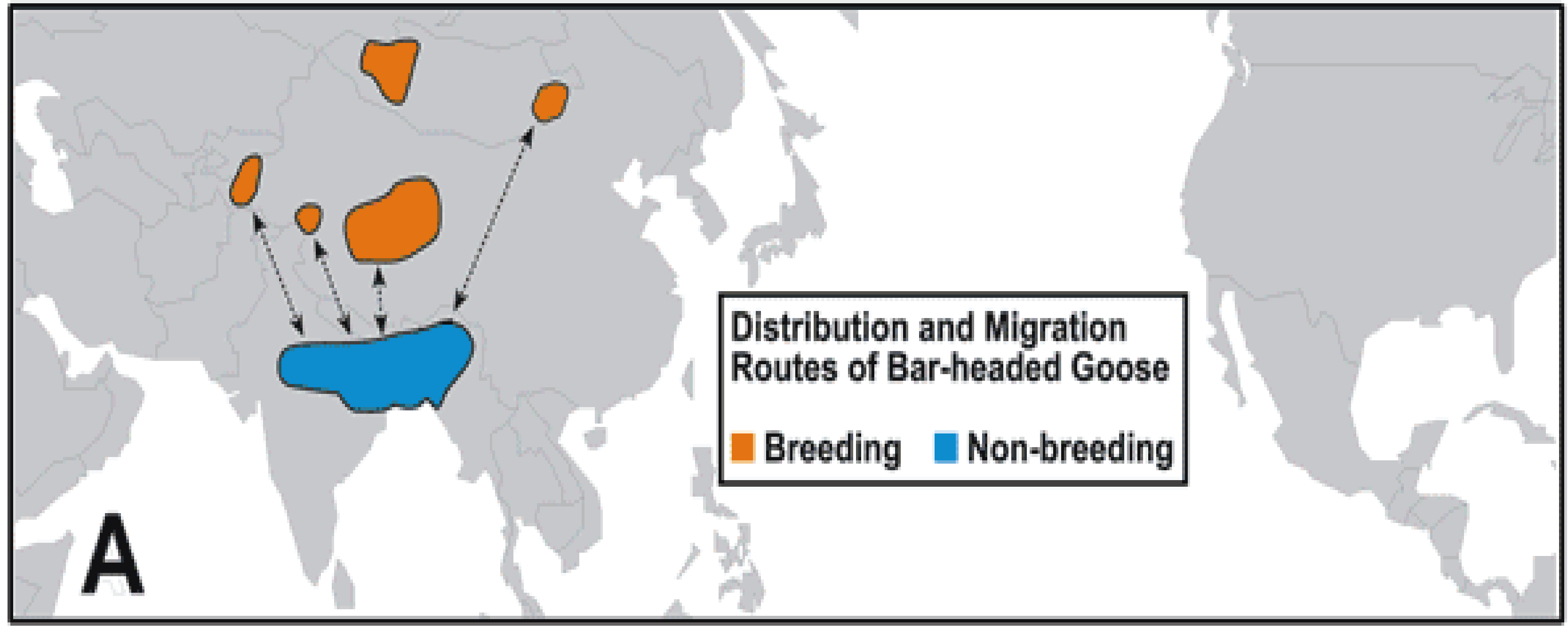


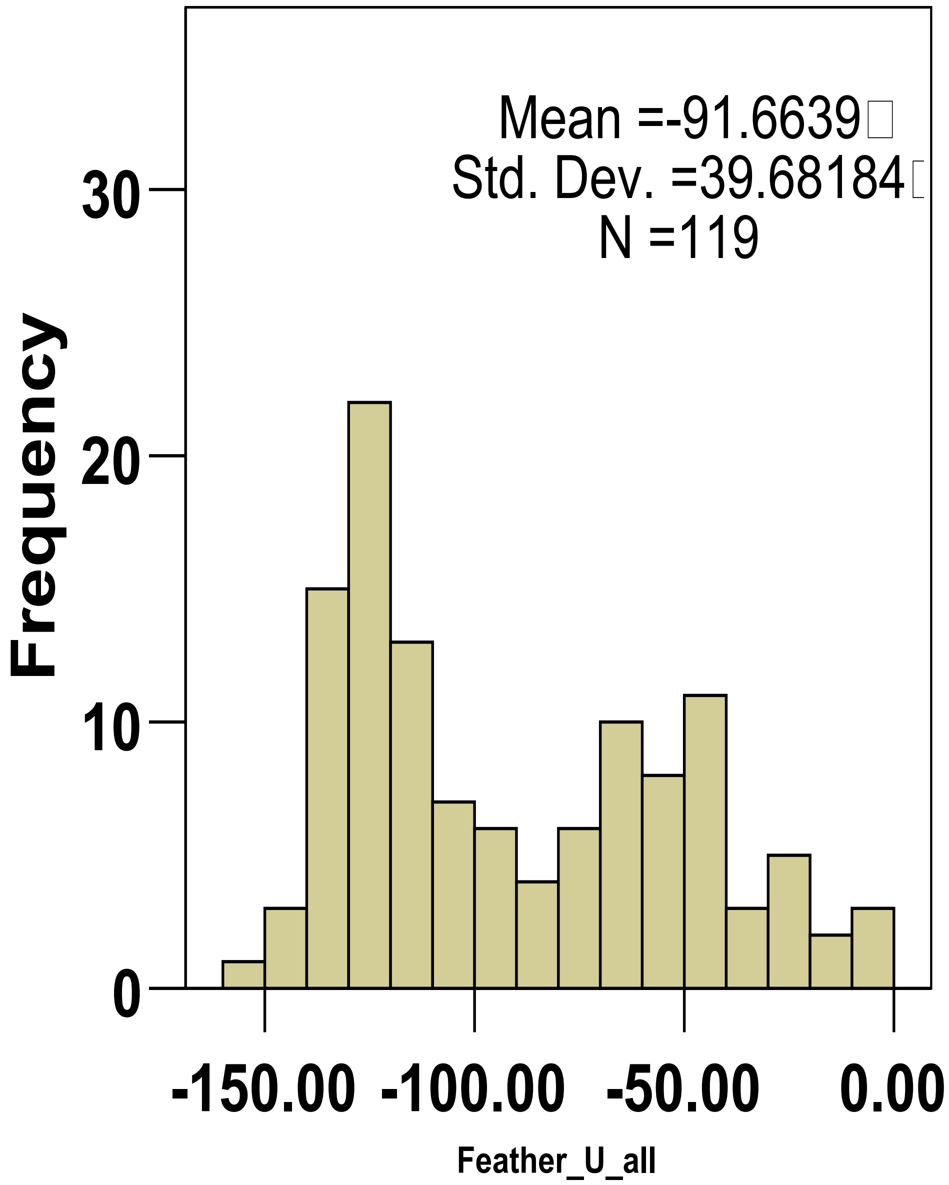
Growing season contours
Political boundaries
Growing Season Precipitation
δ D (‰, VSMOW)
-167 to -142
-142 to -116
-116 to -91
-91 to -66
-66 to -41
-41 to -16
-16 to 8
8 to 33

3 useable zones?



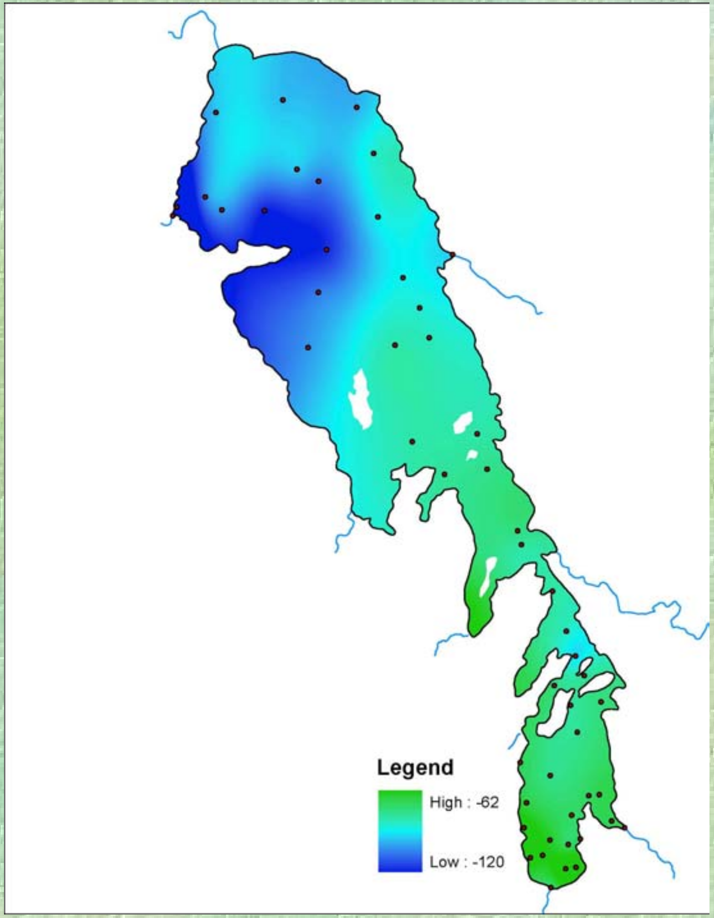
Of use for N-S movements





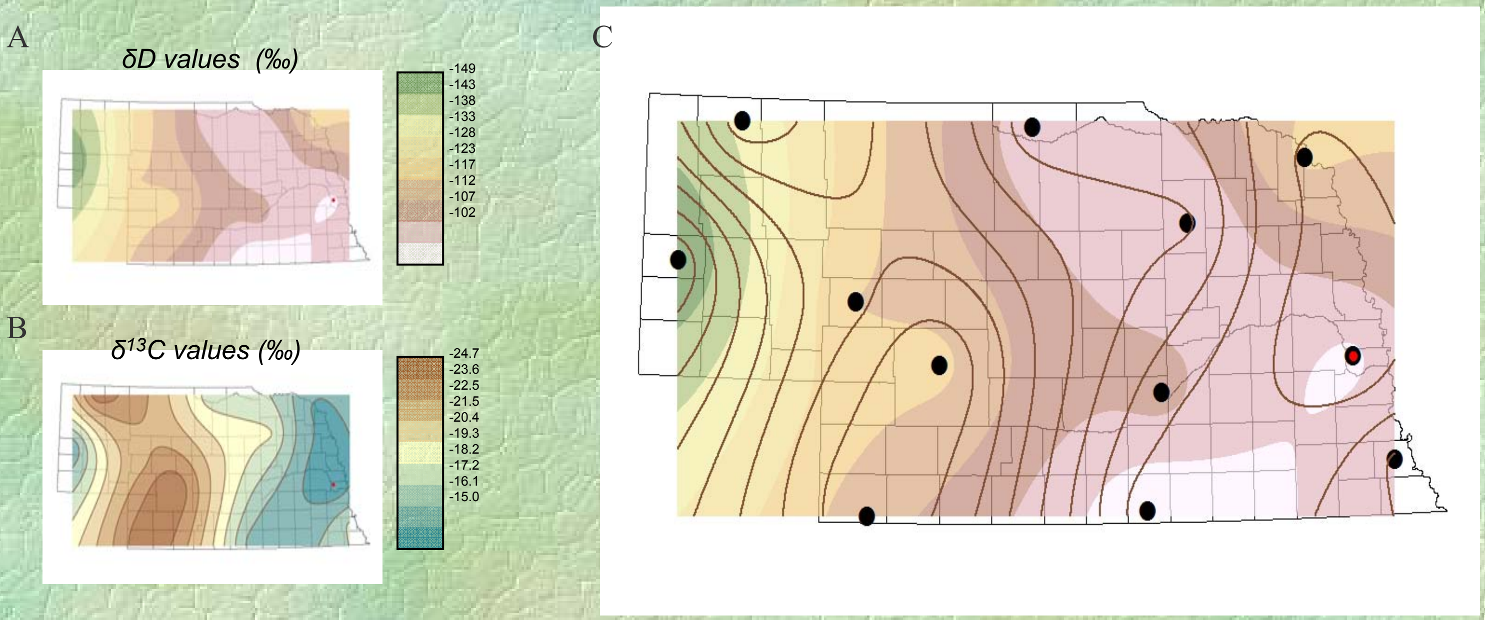
Mean =-91.6639
Std. Dev. =39.68184
N =119
Frequency
30
20
10
0
-150.00
-100.00
-50.00
0.00
Feather_U_all

Freshwater isoscapes (δD)?



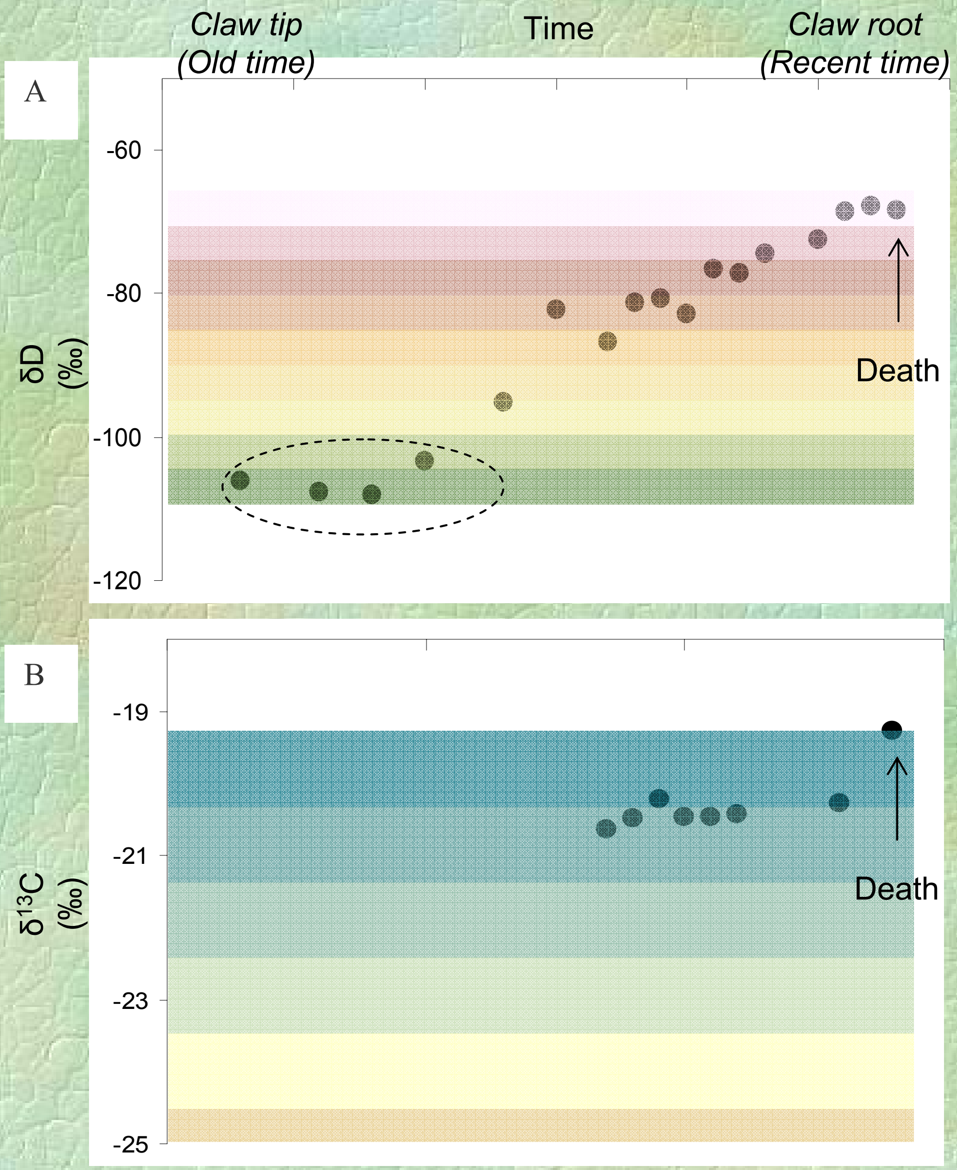
Scaling down: Can we use more local isoscapes?

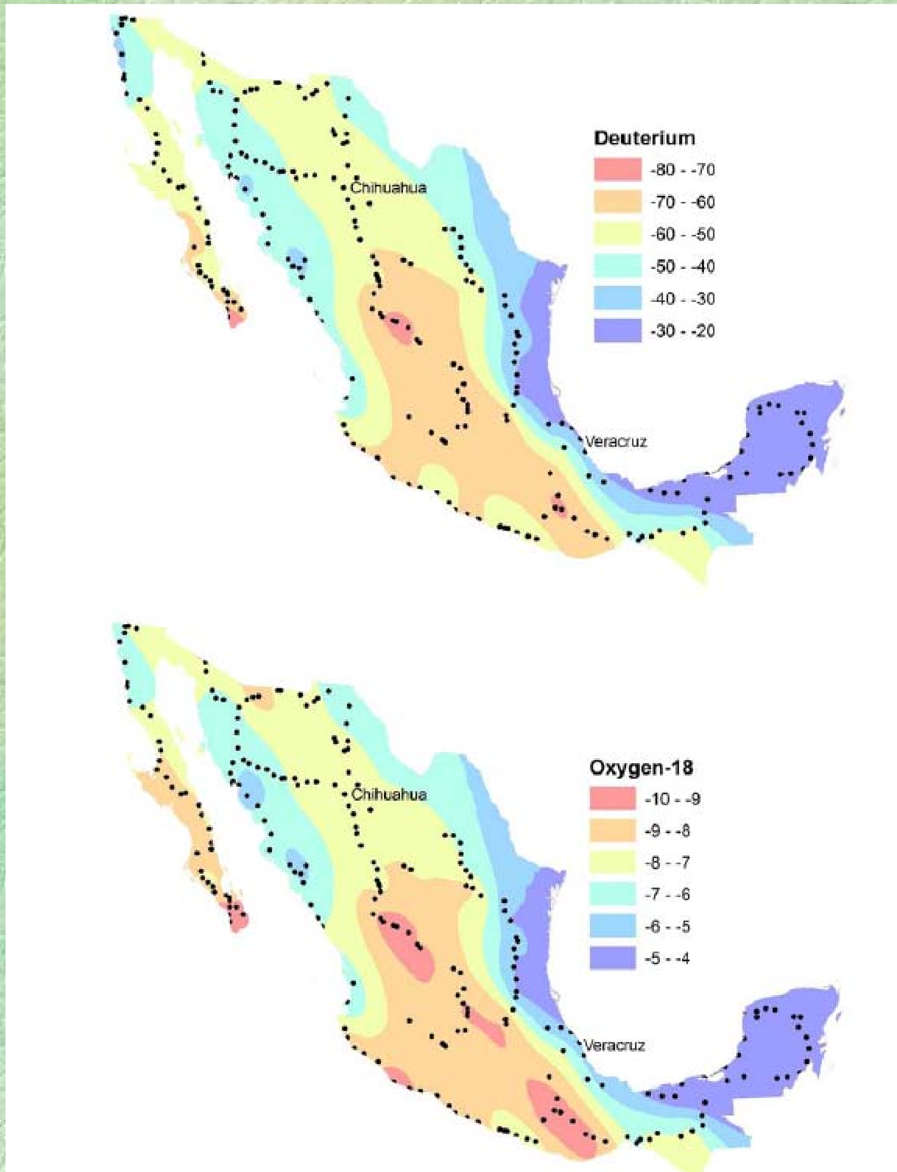
Local-scale isoscapes: Nebraska
Here is a "deer isoscape"

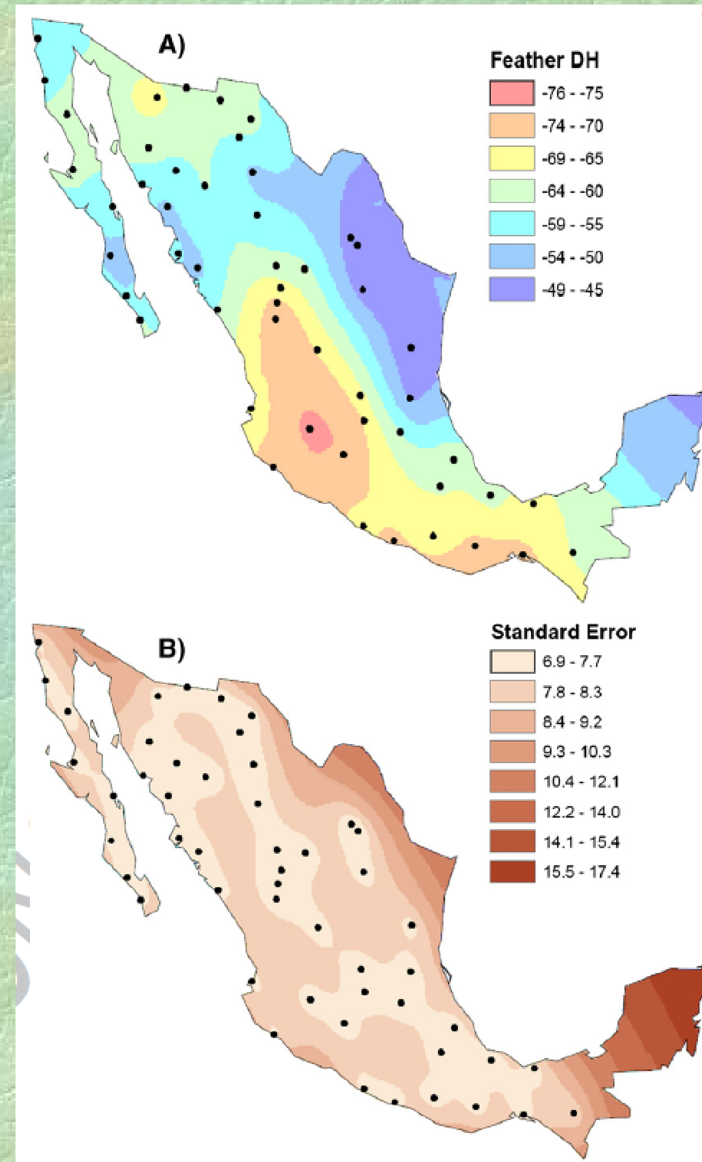


With Larkin Powell

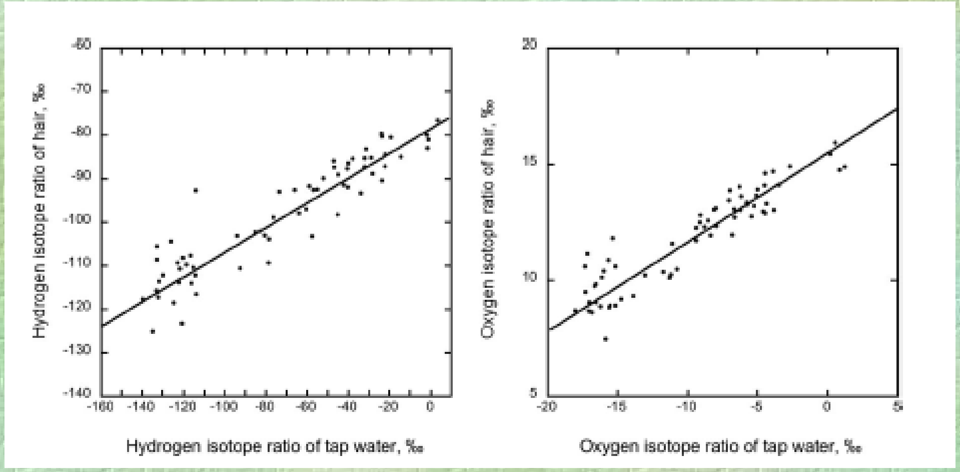
Travels of an unfortunate cougar




Deuterium
-80 - -70
-70 - -60
-60 - -50
-50 - -40
-40 - -30
-30 - -20
Chihuahua
Veracruz
Oxygen-18
-10 - -9
-9 - -8
-8 - -7
-7 - -6
-6 - -5
-5 - -4
Chihuahua
Veracruz


A)
Feather DH
-76 - -75
-74 - -70
-69 - -65
-64 - -60
-59 - -55
-54 - -50
-49 - -45
B)
Standard Error
6.9 - 7.7
7.8 - 8.3
8.4 - 9.2
9.3 - 10.3
10.4 - 12.1
12.2 - 14.0
14.1 - 15.4
15.5 - 17.4

Human Hair



Ehleringer et al. (PNAS 2008)

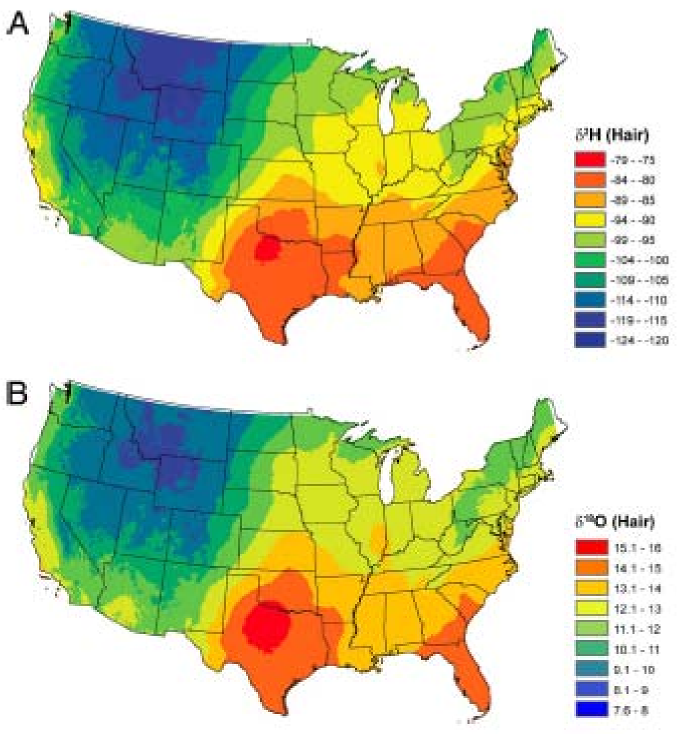


Fig. 3. Geographic Information System-generated maps of the predicted average H isotope ratios (δ^2H_h) *(A)* and average O isotope ratios ($\delta^{18}O_h$) *(B)* of human scalp hair across the coterminous United States.

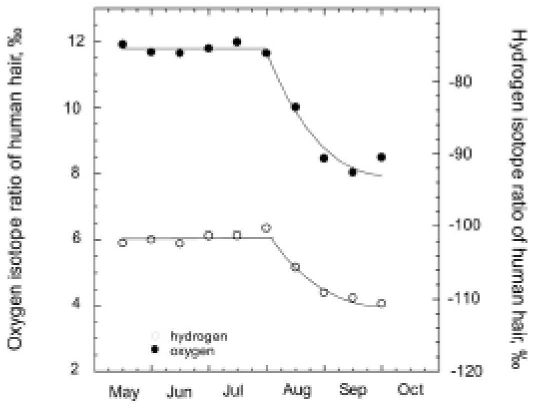


Fig. 4. Time sequence plots of the H (δ^2H_h) and O ($\delta^{18}O_h$) isotope ratios of human scalp hair along a basal-to-tip transect for an individual that moved from Beijing, China, to Salt Lake City, Utah.

Murder investigation …

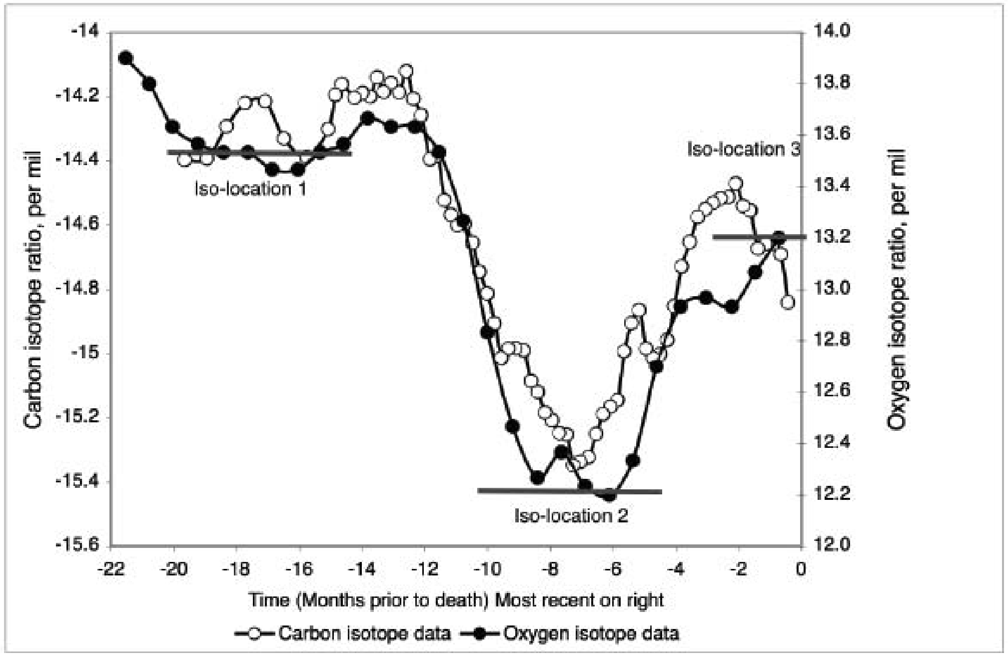


Figure 10. A plot of the carbon and oxygen isotope data measured from hair from the Sierra Nevada murder victim as a function of time prior to the victim's death with three iso-locations marked Time was calculated based on an average growth rate of 0.4 mm/day. Data are 3-point running means. Iso-locations are those regions where it is suggested that the victim had resided for a period of time.

Human tooth isoscape …

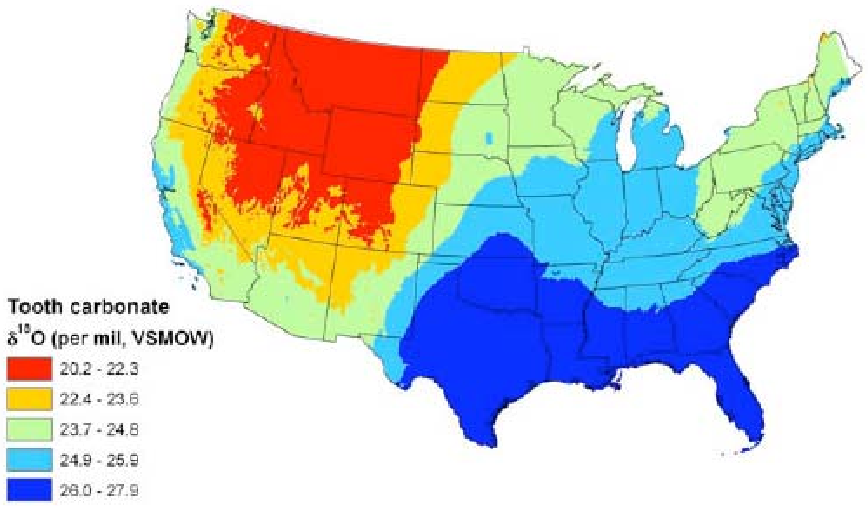
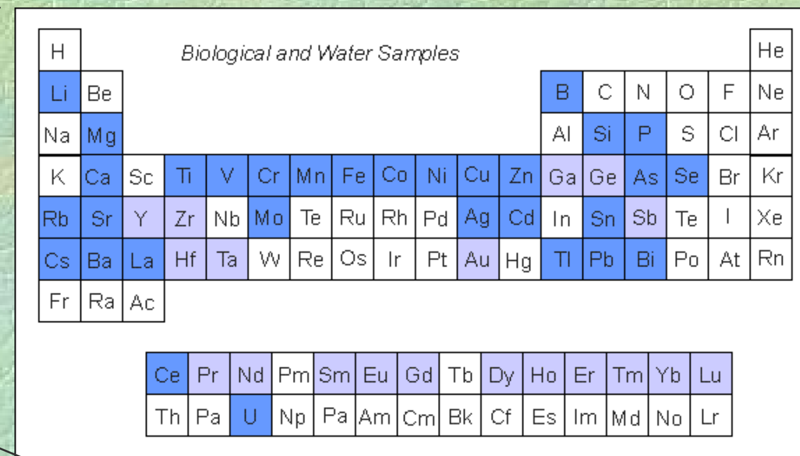
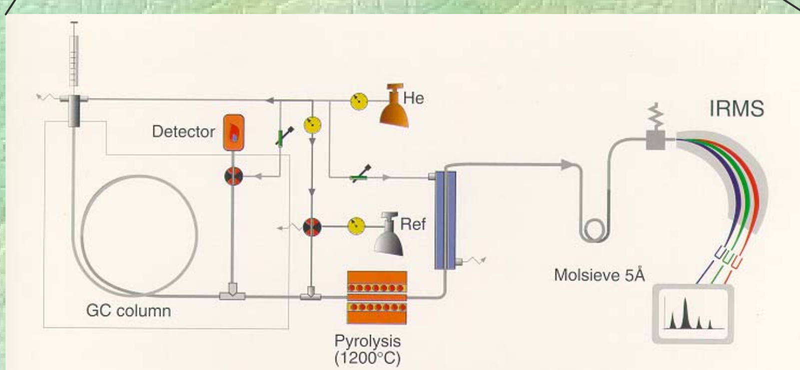


Figure 6. The predicted distribution of oxygen isotope ratios of carbonates in enamel from human teeth across the contiguous USA.

Trace element/heavy isotope





Compound specific Mass spectrometry